SCHMIDT ASTRONOMY AND THE SPACE TELESCOPE

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ABSTRACT: The Space Telescope is described from the viewpoint of its interaction with Schmidt telescopes, specifically with regard to the planning and interpretation of observations and to the construction of the Guide Star Selection System.

I. INTRODUCTION

It is entirely appropriate that this gathering of astronomers who are in one way or another concerned with the applications of Schmidt telescopes should devote significant attention to the Space Telescope (ST). Indeed, I can think of no better example of the complementarity of greatly differing techniques in optical astronomy than one finds in the interplay between Schmidt telescopes and the ST. Obviously, Schmidts have played and will continue to play enormous roles in the identification of the problems (as well as the specific objects) that we expect to study with the ST. Additionally, examination of the surprises that we must reasonably (even conservatively) expect to encounter with the ST will require the use of Schmidts both for immediate follow-up and for the planning of subsequent observations. Finally, the large number of guide stars necessary to point and stabilize the ST can best be located with astrometric techniques based on the use of all-sky Schmidt surveys.

II. ST INSTRUMENTATION AND CAPABILITIES

The concepts, goals, and capabilities of the ST have been described in detail in a number of generally available collections (e.g. Hall 1982; Longair and Warner 1979; Macchetto, Pacini, and Tarenghi 1979). The advances that may be expected to come from the ST originate in its wide spectral coverage (i.e. 10000 A to 1150 A), from its outstanding resolution (better than 0.06 arc-sec [FWHM] at 6330 A, correspondingly higher in the ultraviolet), from its operation as a long-lived (15 year) observatory that is accessible (by open solicitation and peer review) to

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the entire astronomical community, and from its versatility (which arises from the availability of six observing instruments and from the possibility of space-shuttle revisits for instrument repair or replacement or even for ground refurbishment of the entire telescope).

The telescope itself, which is a 2.4-meter Ritchey-Chrétien instrument with a focal-plane scale of 3.58 arc-sec/mm, has pointing stability commensurate with its optical quality and is capable of integrating sufficiently to reach magnitudes as faint as 28. The initial complement of science instruments for ST, which are described in considerable detail in the references cited above, consists of the Wide Field/Planetary Camera, the development effort for which is led by J. A. Westphal at the California Institute of Technology; the Faint Object Camera, by F. Macchetto at the European Space Agency; the High Resolution Spectrograph, by J. C. Brandt at the Goddard Space Flight Center (NASA); the Faint Object Spectrograph, by R. J. Harms at the University of California at San Diego; and the High Speed Photometer, by R. C. Bless at the University of Wisconsin. Additionally, a sixth configuration, which is achieved by using one of the three Fine Guidance Sensors of the ST as an observing instrument, is under development by the Astrometry Team, led by W. H. Jefferys at the University of Texas.

In preparation for the launch of the ST in 1986, the instrumentation described above (as well as the supporting ground systems) is presently in advanced stages of preparation. The institutional basis for the operation of the ST will be provided by the Space Telescope Science Institute (ST ScI), which is responsible for defining the science program of the ST, for supporting all scientific (and some operational) aspects of ST observing and data reduction, and for maintaining a scientifically useful archive of ST data (see Hall 1982 for details). It is expected that the ST ScI will call for ST observing proposals early in 1985, and so now is an excellent time for each of us to be planning such proposals.

III. ST COMPLEMENTARITY WITH SCHMIDT TELESCOPES

When Schmidts, large reflectors (e.g. the 4-meters), and the ST are considered together (i.e. with respect to resolution, to scale, or to field size), the evident hierarchy, namely Schmidt: large reflector: ST, suggests that a primary mode of doing science is to use the Schmidt as a discovery instrument for the large reflector, which then in turn serves as a discovery instrument for the ST. This surely will be a useful research mode in certain cases, for example, those involving crowded fields (like globular clusters) or compact diffuse objects (e.g. specific small structures in nebulae). However, to base research procedures on this three layer hierarchy above is overly simplistic, both because the ST is so dramatically different from either kind of ground-based telescope and because time on large reflectors is so scarce.

Specifically, if we look at the ratios of resolution, scale, or field size for the case Schimdt-to-large-reflector and for the case large-reflector-to-ST, we see that the first set of numbers is much smaller than the second, which is a quantitative way of showing that from the vantage point of ST performance, Schmidts and large reflectors are somewhat similar. Therefore, we may realistically expect to find classes of problems for which the Schmidt alone is an entirely adequate discovery instrument for ST observing, for example the ST observations of a QSO discovered with a Schmidt, possibly one equipped with an objective prism. These lines of reasoning suggest that ST programs will frequently rely directly on Schmidts much as other modes of research do, namely as a discovery and planning instrument (cf. the early paper in this volume), and that this usage mode is likely to be quite heavy.

The availability of time on large reflectors is already insufficient to meet the needs of the astronomical community, and it may be expected that pressures generated by the ST will make this situation worse. Furthermore, even for such telescopes equipped with large scale cameras (scales of the order of 6 to 12 arc-sec/mm and fields of the order of one degree), the speed of the photographic process and the scheduling constraints are such that the amount of direct photographic work being done with such configurations is decreasing, while an approximately compensating amount of direct imaging is being done with small field electronic cameras (CCDs and the like). This practice is yet another factor that makes the Schmidt telescopes a major wide field resource for supporting ST observing.

One may also observe that while the competition for Schmidt observing time is heavy, the oversubscription is still considerably less than for the large reflectors.

While my next remark is clearly unnecessary for the Schmidt specialists here, for the more general audience who may tend to think of the Schmidts in terms of the published standard surveys, I wish to point out yet again the versatility of the Schmidt telescope. It can be configured for direct photography or for (slitless) spectrographic work at a variety of resolutions (ranging from that just sufficient to identify emission line objects to that adequate to do MK spectral classification). A large variety of filters are generally available, and an important development of the last decade is the existence of narrow-band interference filters covering fields several degrees in size. Finally, image growth can be controlled by exposure time so as to obtain very nicely exposed images of specific phenomena; for example, a short H-alpha exposure will produce an excellent image of elephant trunks (in H II regions) that are totally blackened on the standard surveys.

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IV. THE GUIDE STAR SELECTION SYSTEM

One of the most important interactions between the ST and Schmidt astronomy lies in the efforts associated with the Guide Star Selection System (GSSS). The ST contains an inertial system (based on gyroscopes and reaction wheels) sufficient to point to within about one arc-min of a desired target and to hold there with a stability of the order of 0.1 arc-sec per second (of time). Obviously, such performance is sufficient only for rough pointing; and the more precise pointing required by the excellent imaging properties of the ST (see above) will be obtained by reference to off-axis guide stars.

The required measurements on the guide stars are made with the Fine Guidance Sensors (FGS), which are optical interferometers that furnish error signals to the pointing and control system of the ST. The area accessible to each FGS (69 square arc-min) is sufficiently small that relatively faint stars ($9<V<14.5$) will routinely need to be used as guide stars. Furthermore, the possibility that the pointing uncertainty cited above (about 1 arc-min) may lead to the acquisition of an incorrect guide star necessitates the use of photometric information from the FGSs to confirm the correctness of the acquisitions; to support this checking, the GSSS must predict the magnitudes of guide stars to a precision of 0.4 magnitudes. Finally the requirement that GSs be astrometrically sufficient for reliable (3 sigma success probability) positioning of targets in the smallest acquisition aperture (2 arc-sec on the High Resolution Spectrograph) leads to the requirement that the GS-target separations be known to within 0.33 arc-sec. The performance of the GSSS at the galactic poles, where there are relatively few appropriate guide stars, has been addressed by Soneira and Bahcall (1981), who show that the ST system performance goal of 85 per-cent successful acquisitions is generally achievable.

The approach adopted to meeting the above requirements is based on photographic photometry and astrometry using Schmidt plates. The properties of the plate material is given in Table 1. The measuring devices, which are Perkin-Elmer 2020G PDS scanning microdensitometers, accomodate plate sizes up to 50 cm (square) and have scanning speeds up to 200 mm/sec. The nominal precision of these machines as manufactured is 5 microns, which is insufficient to achieve the required astrometric precision for plate scales of 67 arc-sec/mm; and so we are increasing the precision to 1 micron by installing a new optical encoding system based on Hewlett-Packard (5501A) laser interferometers in place of the original encoders. This and other needed PDS modifications are described in Kinsey (1983).

The astrometric error budget adopted allocates 0.25 arc-sec of the 0.33 arc-sec total to plate measuring, centroiding, and reduction to an astrometric reference catalog; the remainder is allocated to proper motion. The most relevant experiments available to date are those conducted on Palomar and SRC plates of the Praesepe astrometric standard region (Russell 1978; also private communication) by Jane Russell at the

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ST ScI. The results of these experiments, which were analyzed with the "Yale" centroider (e.g. Chiu and van Altena 1979; also van Altena private communication) and a standard astrometric reduction program, support pair separations within the 0.25 arc-sec allocation; and additional experiments, currently in progress, are dedicated to verifying that this performance is achievable over the entire sky.

Table 1

Schmidt Survey Material Used in the GSSS

SRC-J Survey	- GG 395 + IIIaJ on SRC Schmidt; - 606 plates covering area south of −20° on 5° centers. - mean epoch 1976 - copies of SRC A grade exposures
SRC-J Survey Equatorial Extension	- GG 395 + IIIaJ on SRC Schmidt - 288 plates covering equator through −15° on 5° centers. - mean epoch 1981 - copies of SRC A or B grade exposures*
Palomar Quick V	- Wratten #12 + IIaD - 583 plates covering +6° through +90° on same 6° centers as original Palomar Survey - mean epoch 1982 - original plates; 20 min (nominal) exposure on "best effort" basis; limiting magnitude about V=19.

*Mixture of A and B grade plates being adjusted to meet GSSS development schedule.

The performance of the GSSS near the edges of Schmidt plates is of particular concern, as important objects surely will lie there; and we must even expect cases in which ST targets and their guide stars are on adjacent plates. The generous overlap that exists in the southern surveys (e.g. 6.6 degree plates on 5 degree centers for the SRC J surveys) makes this a minimal problem there; however, for the Palomar material (6.6 degree plates on 6 degree centers), astrometric overlap solutions will routinely be required.

As I indicated above, proper motions are a particular concern for the GSSS. Table 2, which is based on proper motions of 0.019 arc-sec per year at low latitudes and 0.036 arc-sec per year at high latitudes (cf. adopted from the Radcliffe catalog of proper motions; also Harrington, private communication), on Gaussian combination with an 0.25 arc-sec measuring error (including reduction to the sky), and the mean plate epochs given in Table 1, shows that GSSS performance in significantly large areas of the southern sky will be out of specification (0.33 arcsec) by 1990, i.e. about five years after ST launch. Note that the similar problem for the northern sky does not become serious until significantly later (circa 1995) because we shall be able to incorporate the new Palomar sky survey, scheduled to begin in 1984, into the GSSS.

Table 2

EFFECTS OF CUMULATIVE PROPER MOTION
Combined with Measuring and Transofrmation Error of 0".25

Survey	Mean Epoch	Assumed Proper Motions*	GSSS Performance 1985	1990	1995
SRC	1976	0".019/yr	0".303	0".365	0".439
		.036	.409	.563	.728
SRC-Ext	1981	.019	.261	.303	.365
		.036	.289	.409	.563
Palomar	1983	.019	.253	.283	.338
		.036	.260	.355	.499

*Upper and lower entries correspond to low and high galactic latitudes, respectively.

The long operational life of the ST requires that the GSSS take steps to assure performance within the ST specifications well into the twenty-first century. While enough exciting new things are happening in astrometry that creating a detailed 20 year plan at this time would be foolish, it is clear that, at least in the short run, that matter of maintaining GSSS performance is best pursued by obtaining recent epoch Schmidt plates (i.e. ones for which proper motions may be neglected).

One photoelectrically measured photometry sequence (generally six stars covering the required range, measured in B and V, and having a precision of at least 0.05 mag) per Schmidt survey plate center will be used to calibrate the photographic photometry that the GSSS must do to support the correct identification and acquisition of guide stars. These data, which are a combination of sequences form the literature and new observations, are already about 85% complete; and we do intend to present the complete set of sequences as a published paper.

V. THE GSSS STAR CATALOG

The logical processes of planning and scheduling ST observing sequences requires the use of large quantities (say, months) of

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approximate guide star information early in each ST planning cycle, i.e. before detailed and precise GSSS results could possibly be made available. Therefore, the GSSS Star Catalog is being constructed to support this ST planning requirement. The catalog will be nearly complete over the set of possible guide stars, i.e. complete to 15th mag at high and intermediate galactic latitudes and at lower latitudes magnitude-limited at about 13.5 or 14th mag, corresponding to a surface density of about 1000 stars per square degree. About 20,000,000 entries are expected in the catalog, each with a precision of about 0.5 to 1.0 arc-sec in relative position (about 3 arc-sec absolute) and 0.6 mag in brightness.

The catalog will be constructed from so called "coarse scans" (entire plates scanned with the PDSs at low resolution, generally 50 microns, corresponding to 3 arc-sec pixels) of the plate material described in Table 1. This work, which has already begun using prototype software developed at the ST ScI as well as that provided by our colleagues (particularly the COSMOS group at Edinburgh), is to be completed before ST launch, and we expect to publish the catalog in a scientifically usable form as soon thereafter as possible.

VI. RECOMMENDATIONS

Our gathering here is a unique forum for generating ideas related to the use of Schmidt telescopes, and especially to making new Schmidt surveys. Therefore, I wish to take this opportunity to indicate three directions that, if adopted, would benefit all of us by best supporting the ST, in the first two cases by improving the precision and throughput of the GSSS, in the third case by the general support of ST research:

1. Make a new southern survey with a mean epoch of about 1990 so as to provide a set of southern plates with small accumulated proper motions, for soon after that time the proper motions accumulated in the original southern survey will cause GSSS errors that present an operational problem for the ST.

2. Make new surveys on 5 degree centers so as to minimize the necessity of performing astrometric overlaps to plan ST observations, for such overlaps reduce GSSS throughput (and possibly precision).

3. Adopt usage and scheduling policies for Schmidt telescopes such that significant and convenient amounts of observing time are available for individual observing programs dedicated to planning ST programs and to interpreting ST results.

It is, of course, painfully clear that item 3, astronomical research, is in priority contention with items 1 and 2, new surveys. This is presumably a theme that will arise many times at this conference, and I hope that the special needs of ST will be considered as it is resolved.

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VII. FUNCTIONAL RELATIONS TO OTHER PROGRAMS

The interactions between the Schmidt-ST activities that we have been considering and other programs of astronomical instrumentation will generally be driven by specific research projects; nevertheless, an overview is evident. In addition to its obvious uses for stellar statistics, the GSSS Star Catalog may be useful in supporting various all-sky astrometric programs, of which the Hipparcos/Tycho mission, discussed elsewhere in this volume, is one possibility. Additionally, the engineering and astronomical constraints that have led to the requirements for a GSSS for the ST will be pertinent to other planned or proposed astronomical satellites, and so not only the GSSS Star Catalog but also some functional details of the GSSS design may be useful in these newer telescopes.

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DISCUSSION

R.D. CANNON: Dr.Lasker has referred to the desiderability of the UK Schmidt Telescope being used to re-survey the southern sky in the 1990's. While many people feel that this would be a very valuable project for many reasons, I should make it clear that the scientific programme of UKST is determined by the British telescope time assignment committees, and that it will be necessary to make the case that re-surveying the southern sky represents the best scientific use of the telescope at that time.

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