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ABS: This manual is a guide for astronomers who intend to use the High Speed Photometer (HSP), one of the scientific instruments onboard the Hubble Space Telescope (HST). All the information needed for ordinary uses of the HSP is presented, including: (1) an overview of the instrument; (2) a detailed description of some details of the HSP-ST system that may be important for some observations; (3) tables and figures describing the sensitivity and limitations of the HSP; (4) how to go about planning an observation with the HSP; and (5) a description of the standard calibration to be applied to HSP data and the resulting data products.

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HIGH SPEED PHOTOMETER INSTRUMENT HANDBOOK

Version 2.0

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N92-17497#

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Chapter 1: Introduction

1.1 How to Use This Manual

This manual is a guide for astronomers who intend to use the High Speed Photometer (HSP), one of the scientific instruments onboard the Hubble Space Telescope (ST). All the information needed for ordinary uses of the HSP is contained in this manual, including:

(1) an overview of the instrument (Chapter 2),

(2) a detailed description of some details of the HSP-ST system that may be important for some observations (Chapter 3),

(3) tables and figures describing the sensitivity and limitations of the HSP (Chapter 4),

(4) how to go about planning an observation with the HSP (Chapter 4), and

(5) a description of the standard calibrations to be applied to HSP data and the resulting data products (Chapter 5).

An HSP neophyte should begin by reading Chapters 2 and 4 to get an overview of the instrument and what it can do. Chapter 4 also shows how to write a proposal requesting observing time using the HSP. Chapter 5 describes the data products received by the observer. Skimming through Chapter 3 will give some feeling for the complications which may arise.

The HSP sophisticate will refer mainly to Chapters 3 and 4, and may often find that the careful construction of complicated observing programs is driven by the constraints described in Chapter 3.

Some observing programs will inevitably require more detailed information about the HSP than is given here. For example, it is possible to write special purpose programs for a microprocessor inside the HSP that controls observing sequences, but this manual does not contain enough information to determine precisely what can and cannot be done with such programs. If you require such detailed information, it is available either from the Space Telescope Science Institute or from the documents listed in the bibliography of this manual.

As time passes, there will undoubtedly be changes in this manual. Chapters 3 and 4 are especially vulnerable to changing as our knowledge of the instrument improves. Consequently, users should be wary of using outdated versions of the manual.

Suggestions for improvements are welcome and should be addressed to the author.

1.2 Acronyms

Acronyms are a necessary, if often overused, aid in reducing the length of NASA documents. The following acronyms may rear their heads in this manual:

Table 1–1: *Acronyms*

A/D	Analog to Digital
BD	Bus Director
CVZ	Continuous Viewing Zone
FGS	Fine Guidance System
FOC	Faint Object Camera
FOS	Faint Object Spectrograph
GSFC	Goddard Space Flight Center
GHRS	Goddard High Resolution Spectrograph
HSP	High Speed Photometer
IDT	Image Dissector Tube
NASA	National Aeronautics and Space Administration
NSSC-1	NASA Standard Spacecraft Computer
ODS	Optical Detector Subsystem
OTA	Optical Telescope Assembly
PAD	Pulse Amplitude Discriminator
PMT	Photomultiplier Tube
RAM	Random Access Memory
ROM	Read-Only Memory
SCUM	System Controller User's Manual
STSDAS	Science Data Analysis System
SOGS	Science Operations Ground System
ST	Hubble Space Telescope
STScI	Space Telescope Science Institute
TAV	Target Acquisition and Verification
TBD	To Be Determined
TDRSS	Tracking and Data Relay Satellite System
UV	Ultraviolet
WF/PC	Wide Field/Planetary Camera

1.3 Acknowledgements

The High Speed Photometer was designed and built at the University of Wisconsin by Robert C. Bless (Principal Investigator) with scientific guidance from the HSP Investigation Definition Team: Joseph F. Dolan, James L. Elliott, Edward L. Robinson, and Wayne van Citters. Among those making major contributions to the design, construction, and testing of the HSP were Evan Richards, Jeff Percival, Fred Best, Dave Birdsall, Gene Buchholtz, Scott Ellington, Don Finegan, Ed Hatter, Sally Laurent-Muehleisen, Matt Nelson, Bill Phillips, Jerry Sitzmann, Mark Slovak, Colleen Townsley, Andrea Tuffli, Mark Werner, Doug Whitely, and others, to whom I apologize for their omission from this list.

Much useful criticism of the HSP Instrument Handbook was provided by Bob Bless, Joe Dolan, Howard Bond, and Lisa Walter; however, any remaining problems are the responsibility of the author.

Chapter 2: Overview of the HSP

The High Speed Photometer (HSP) exploits the capabilities of the ST by making photometric measurements over visual and ultraviolet (UV) wavelengths at rates up to 10^5 Hz and by measuring very low amplitude variability (especially for hotter stars in the UV). A secondary purpose of the instrument is to measure linear polarization in the near UV. The HSP has several advantages over similar ground-based instruments:

(1) UV wavelength coverage.
(2) Smaller apertures, permitting higher spatial resolution and reducing the sky background.
(3) No atmospheric absorption or scintillation, leading to higher photometric accuracy and the ability to use very short sample times.

In what follows we will present an overview of the HSP, its optics and detectors, its electronics, its mechanical structure, and finally some observational considerations.

2.1 Summary of HSP Characteristics

Quantum Efficiency:	~0.3–3% (throughput for entire HSP-ST system)
Time Resolution:	10.8 μs (pulse-counting mode, count rate $< 10^6$ cts/s) ~1 ms (current mode, count rate $> 10^6$ cts/s)
Photometric Accuracy:	Systematic errors < 0.1% from V=0 to V=20
Apertures:	0.4, 1.0 arcsec diameter for normal observations 6.0, 10.0 arcsec for target acquisition
Filters:	23 UV and visual filters from 1200 Å to 7500 Å
Polarimetry:	4 UV filters 0.2% polarimetric accuracy
Operation:	Telescope must slew to move star from one filter to another. Slew time ~30–60 s (limits rate at which multicolor photometry is possible). There are 4 filter pairs with beamsplitters which can be used for 2 color photometry without moving telescope; for these filter pairs, can get simultaneous or nearly simultaneous (separated by only 10 milliseconds) 2 color photometry.

2.2 Detectors and Optics Configurations

The HSP has quite an unusual design, in that it has no moving parts. Figure 2-1 shows a sketch of the arrangement of the detectors and optics in the HSP. There are five detectors in the instrument—four image dissector tubes (IDTs) and one photomultiplier tube. The former are ITT 4012RP Vidissectors, two with CsTe photocathodes on MgF_2 faceplates (sensitive from 1200 Å to 3000 Å) and two with bialkali cathodes on suprasil faceplates (sensitive from 1600 Å to about 7000 Å). Each image dissector tube, its voltage divider network, and its deflection and focus coils are all contained in a double magnetic shield within the housing. The photomultiplier is a Hamamatsu R666S with a GaAs photocathode. Three of the image dissectors—the two CsTe tubes (called *UV1* and *UV2*) and one of the bialkali tubes (*VIS*)—are used for photometry. The second bialkali dissector (*POL*) is used for polarimetry,* and a beamsplitter allows the photomultiplier (*PMT*) along with the bialkali photometry dissector (VIS) to be used for simultaneous observations in 2

* Note that the polarimeter also has 1 clear filter which can be used for photometry.

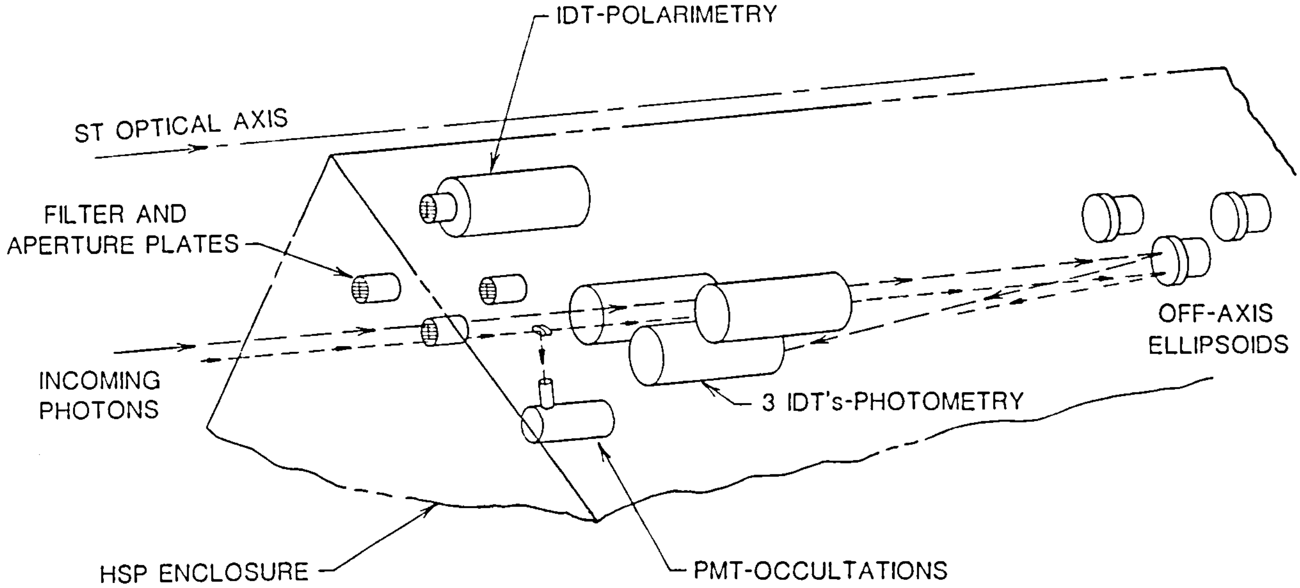

Figure 2–1: *HSP Optics and Detectors*

colors (*e.g.*, for occultations). For convenience, we will refer to the photometric, polarimetric, and PMT "configurations", but in most respects the operation of the various detectors is identical.

For the purposes of the ST proposal forms, the HSP has the following configurations and modes:

Table 2–1: *HSP Configurations and Modes*

Configuration	*Modes*
HSP/UV1, UV2, VIS	SINGLE, STAR-SKY, ACQ, PEAKUP, IMAGE, PRISM
HSP/POL	SINGLE, STAR-SKY, ACQ, PEAKUP, IMAGE
HSP/PMT	SINGLE
HSP/$\langle D_1 \rangle$/$\langle D_2 \rangle$	STAR-SKY
HSP/PMT/VIS	SPLIT

All these modes are discussed in the following paragraphs. The ACQ mode is used for target acquisition and is also discussed in §2.5.1 and in the *HSP Target Acquisition Handbook*. See the *Hubble Space Telescope Phase II Proposal Instructions* for information about how to specify the various configurations and modes on the proposal forms.

2.2.1 *Single-Color Photometry*

Consider first photometric observations, which can be carried out using the mode SINGLE. This mode can be used with any of the 5 HSP detectors. Light from the ST enters the HSP through one

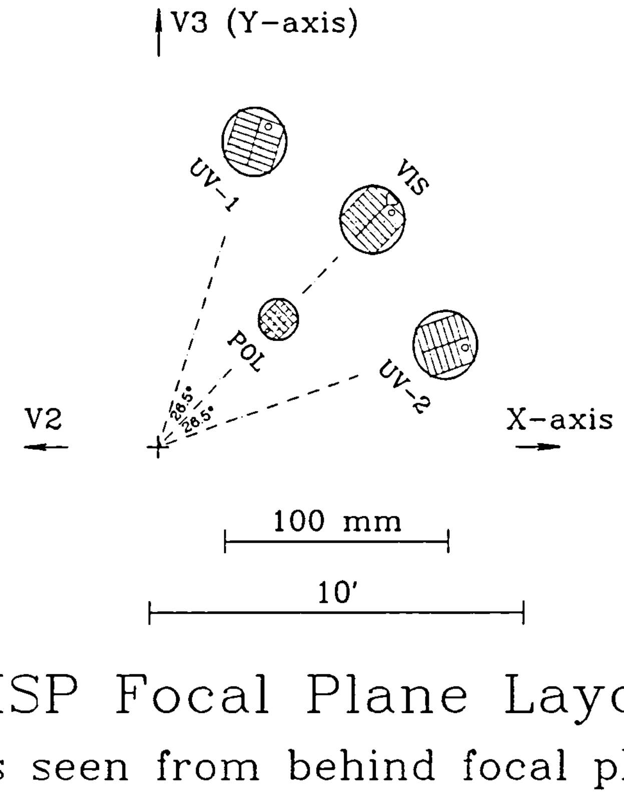

Figure 2–2: *HSP Focal Plane Layout*

of three holes in its forward bulkhead. These holes are all centered on an arc 8.1 arc min off-axis; the focal plane layout for the HSP is shown in Figure 2-2. After passing through a filter (which is about 36 mm in front of the ST focal plane) and an aperture (which is in the ST focal plane), the light is brought to a refocus on the dissector photocathode by a relay mirror—a 60 mm diameter off-axis ellipsoid located about 800 mm behind the ST focal surface. The relay mirrors enable a more efficient use to be made of the ST focal plane available to the HSP than would otherwise be possible, *i.e.*, the image dissectors are too large to place more than two directly in the focal plane. The magnification of the relay mirrors is about 0.65, which converts the $f/24$ bundle entering the HSP to $f/15.6$ at the photocathode, with a corresponding change in scale from 3.58 arcsec/mm to 5.54 arcsec/mm. The off-axis ellipsoids produce images at the photocathode which are about 0.25 arcsec in diameter. The actual intensity distribution at each image is a combination of the geometrical aberrations and the ST point spread function. Since about 70% of the energy in an ST image 8 arcmin off-axis falls within a circle whose diameter is 0.2 arcsec, the total image blur will be about $\sqrt{2}$ times larger than the geometric blur. For this reason, one set of HSP apertures was made 0.4 arcsec in diameter. Images that encompass 90% or more of the energy, however, are more than 0.5 arcsec in diameter. Addition of the effects of worst-case pointing jitter and other uncertainties led to the choice of 1.0 arcsec for the diameter of the second set of apertures. The 0.4 arcsec apertures will be used when the background light is important (*e.g.*, for occultations or for observations of very faint objects); the 1.0 arcsec apertures will be used when the greatest photometric accuracy is desired.

The only unusual feature of the HSP's optical system is its filter-aperture "mechanism" (see Figures 2-3 through 2-7) mounted behind each forward bulkhead entrance hole. Each filter plate contains thirteen filters mounted in two columns positioned 36 mm ahead of the ST focal plane. At this location the converging bundle of light from the ST is 1.5 mm in diameter, well within the

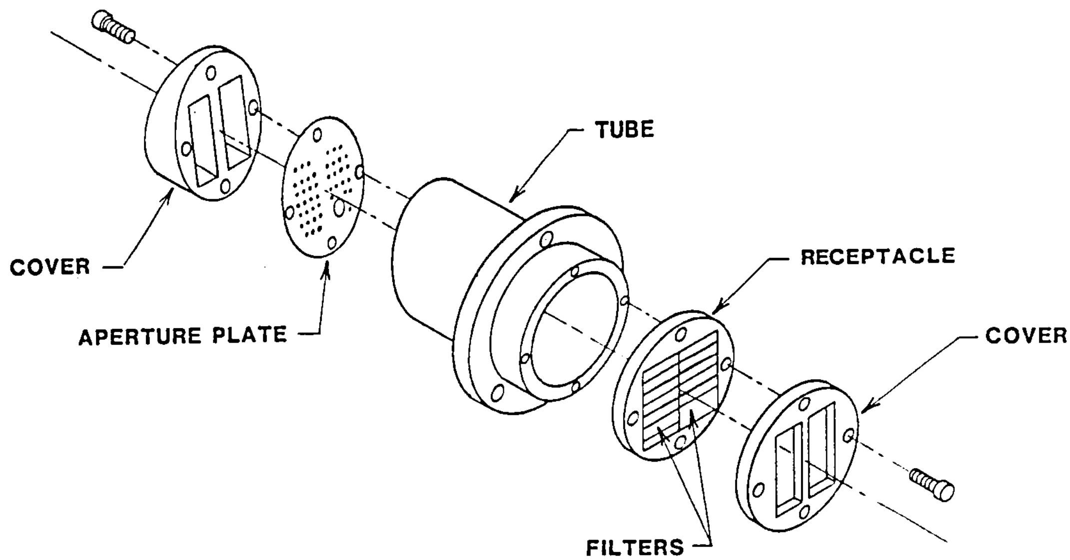

Figure 2–3: *HSP Filter/Aperture Tube Configuration*

3 mm width of each filter; however, since the light bundle is out of focus, small variations in filter transmission with position should not be important. For each filter plate there is an aperture plate, located at the ST focal surface, which contains 48 apertures arranged in two columns that are positioned directly behind the corresponding columns of filters. Nine of the filters are associated with four apertures each—two with diameters of 1 arcsec (280 μm) and two with diameters of 0.4 arcsec (112 μm). Due to space limitations, one filter is associated with only three apertures, and two other filters are associated with two apertures each. The thirteenth filter, of double width, is a clear window and has five associated apertures, including one of 10 arcsec diameter for object acquisition. The VIS detector has one additional aperture which also passes light to the PMT (see §2.2.3).

The ST is commanded to point so that the object's position in the ST focal plane coincides with the particular filter-aperture combination desired. Light from the object is then focused on the dissector cathode by the relay mirror. The resulting photoelectrons are magnetically focused and deflected in the forward section of the image dissector so that the photocurrent is directed through a 180 μm aperture (corresponding to 1 arcsec on the sky). This aperture connects the forward section of the detector to a 12-stage photomultiplier section. Thus with no moving parts, 48 different filter-aperture combinations are available for each photometry detector in the HSP. Not all of these are unique, however, because of duplicate filters and duplicate apertures associated with each filter.

All of the UV filters are multi-layer interference filters of Al and MgF_2 evaporated on MgF_2 substrates for the far ultraviolet, or on suprasil for the near UV. The visual filters consist of Ag and cryolite layers deposited on glass. The substrates are 1/16 inch ($\pm$0.002 inch) thick. The general filter characteristics are listed below in Tables 4-1 and 4-2. Some filters are common to two or more photometry image dissectors for the sake of redundancy and to enable all three channels to be tied together photometrically. Other filters define bandpasses similar to those flown on previous space observatories, while yet others are similar to some in the Wide Field and Faint Object Cameras.

There is one filter on the *POL* IDT (F160LP, see Fig. 2-7) with two 0.65 arcsecond apertures which can be used for photometry. The other filters on *POL* have polarizers and can be used only for polarimetry (§2.2.4).

Figure 2-2 shows the X and Y reference axes that are used if it is necessary to specify a particular orientation for an HSP observation (using the `ORIENT` special requirement) or a special position for a target in an aperture (using the `POS TARG` special requirement). For example, the acceptable range of orientations may be restricted to insure that an aperture to be used for measurement of the sky brightness will not be contaminated by field star. (See §2.5.2 for discussion of sky subtraction using the HSP.)

Notice that filter changes generally require the ST to slew from one aperture to another; this requires about 30 seconds for two apertures on the same IDT and about 60 seconds for two apertures on different IDTs. The slew time determines how rapidly multicolor photometry can be done. There are two exceptions to this restriction: rapid two-color observations can be made either in `PRISM` mode with detectors VIS, UV1, and UV2, or in `SPLIT` mode using PMT and VIS.

2.2.2 Two-Color Photometry with Prisms

On each photometry IDT, there is a beamsplitter/prism combination which divides the light of an appropriately placed target between two 1 arcsec apertures which have different filters (see Figures 2-4 through 2-6). A partially reflecting MgF_2 plate mounted at 45° to the incoming beam transmits part of the incident light to a filter and 1 arcsec aperture. The reflected beam is totally internally reflected by a right angle prism made of suprasil; it then passes through another filter, a suprasil rod (which compensates for the longer path followed by the reflected beam), and another 1 arcsec aperture. In all cases, the transmitted beam passes through the short wavelength filter and the reflected beam goes through the long wavelength filter of the pair.

Using this prism beamsplitter (mode `PRISM` on the proposal forms), it is possible to measure an object's brightness in 2 colors merely by moving the IDT beam from one aperture to the other rather than by slewing the ST, permitting observations in the two bandpasses separated by only about 10 milliseconds rather than by the thirty seconds required for an ST slew. Thus, the prisms permit nearly simultaneous observations in two colors.

Only one pair of filters on each of the 3 photometry IDTs can be used with a prism; Table 4-3 lists the 3 pairs of prism filters. Duplicates of all prism filters are also available as normal (straight through) filters without the intervening prism.

2.2.3 Two-Color Photometry with the PMT

In the `SPLIT` mode, light from the target object passes through a filter (in this case clear suprasil, Fig. 2-4) and on through a 1 arcsec aperture, after which it strikes a Ag-Cryolite beamsplitter at 45° to the incident beam. The mirror reflects red light to the photomultiplier (PMT) via a red glass filter and a Fabry lens. The beamsplitter passes a spectral band in the blue on to a relay mirror and to the VIS image dissector. Truly simultaneous observations can therefore be made at about 7500 Å and 3200 Å.

The PMT detector and the F320N filter on the VIS detector can also be used independently for single-color photometry (§2.2.1). However, there is ordinarily no advantage in doing so because taking data through both filters requires no additional observing time or overhead.

Note that the 45° reflection in both the PMT beamsplitter and the prism beamsplitters introduces significant instrumental polarization in the transmitted beam, so that the count rates for a 10% polarized source will vary by about 2% with the ST roll angle.

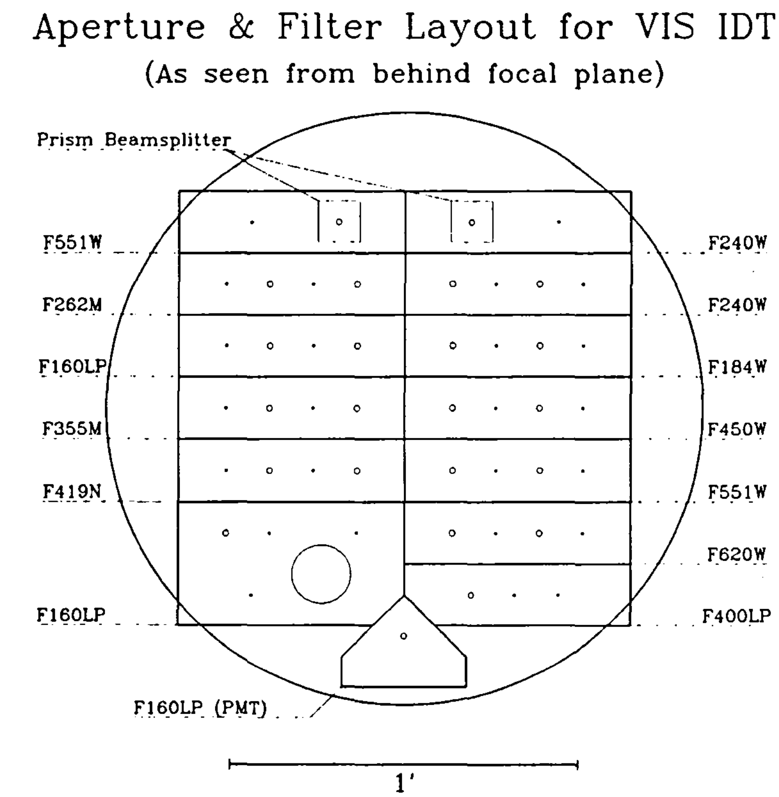

Figure 2–4: *VIS IDT Apertures and Filters*

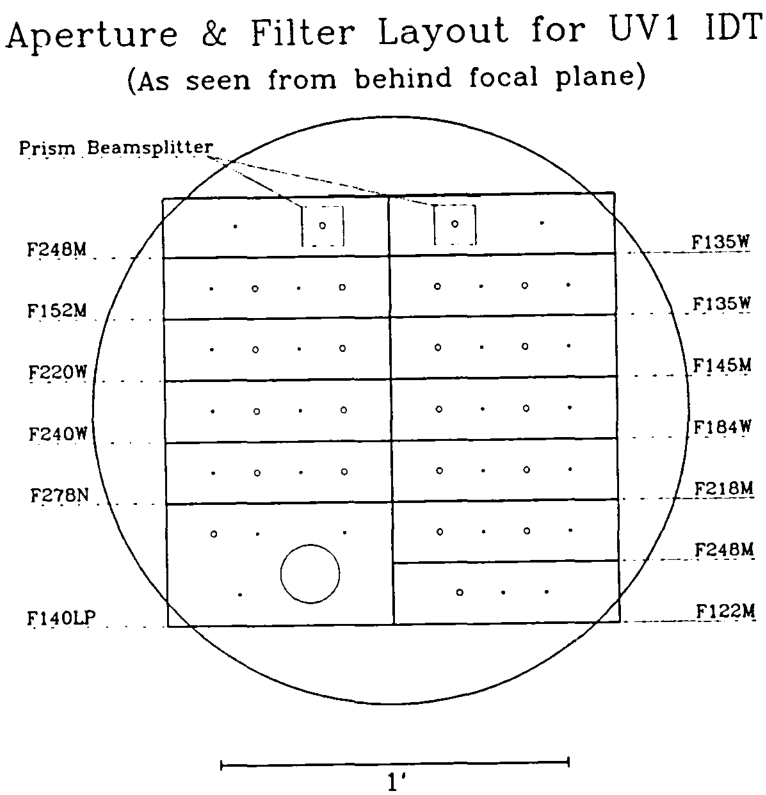

Figure 2–5: *UV1 IDT Apertures and Filters*

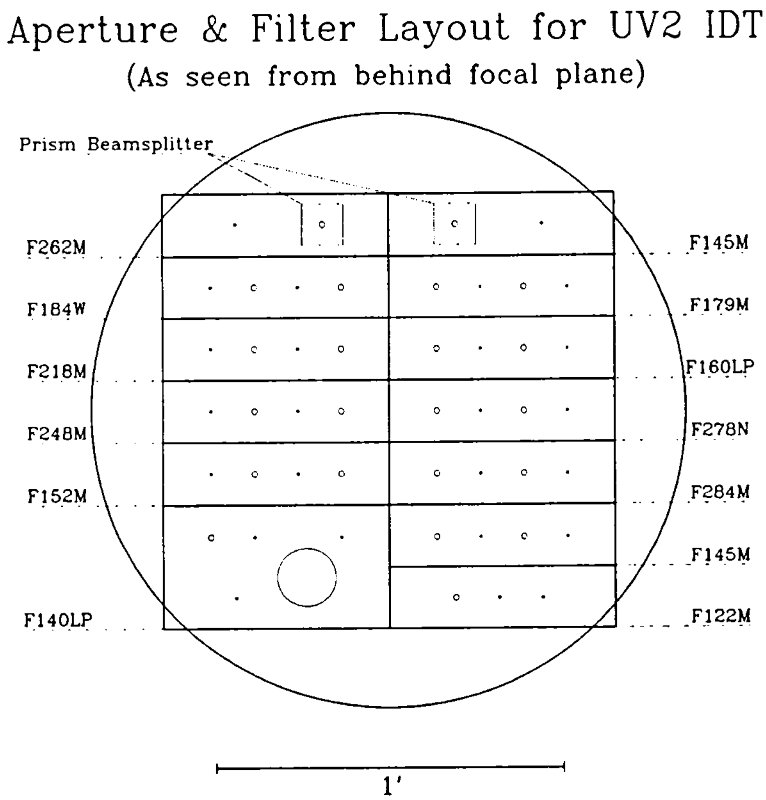

Figure 2–6: *UV2 IDT Apertures and Filters*

2.2.4 Polarimetry

In the HSP/POL configuration, light from the target passes through a filter-aperture assembly (which is only about 4 arc min off-axis) directly to the image dissector; no relay mirror is used. The filter assembly (Figure 2-7) contains four near UV filters (see Table 4-2) across which are four strips of 3M Polacoat with polarizing axes oriented at 0°, 45°, 90°, and 135°. The aperture plate contains a single aperture for each filter-polarizer combination. There is also a clear window with two small apertures, which can be used for photometry, and a 6 arcsec diameter finding aperture. Linear polarization for a particular bandpass is measured by deriving the Stokes parameters Q and U from observations through each of the four polaroids in succession.

The internal IDT aperture for the polarimetric IDT is 180 μm in diameter, the same as for the photometric IDTs; however, because there is no relay mirror to change the plate scale, this corresponds to 0.65 arcsec on the sky. Thus, the internal aperture is slightly smaller than the 1 arcsec focal plane apertures, and the effective aperture diameter for the polarimeter is 0.65 arcsec. This should not affect the accuracy of polarimetry because the ST image is smaller at the polarimeter apertures due to the smaller astigmatism near the optical axis. However, it should be considered when calculating the flux expected from extended sources.

For some observations, the polarimeter on the Faint Object Spectrograph might be better than that on the HSP. For example, the FOS would usually be preferable for a source which has a polarized continuum contaminated by unpolarized line emission. On the other hand, the FOS polarimeter may not be as well-calibrated as the HSP polarimeter during the initial phases of the ST mission. See the *FOS Instrument Handbook* for details on the FOS polarimeter. Observers planning to do polarimetry are encouraged to contact the STScI for advice on which instrument is best for their proposal.

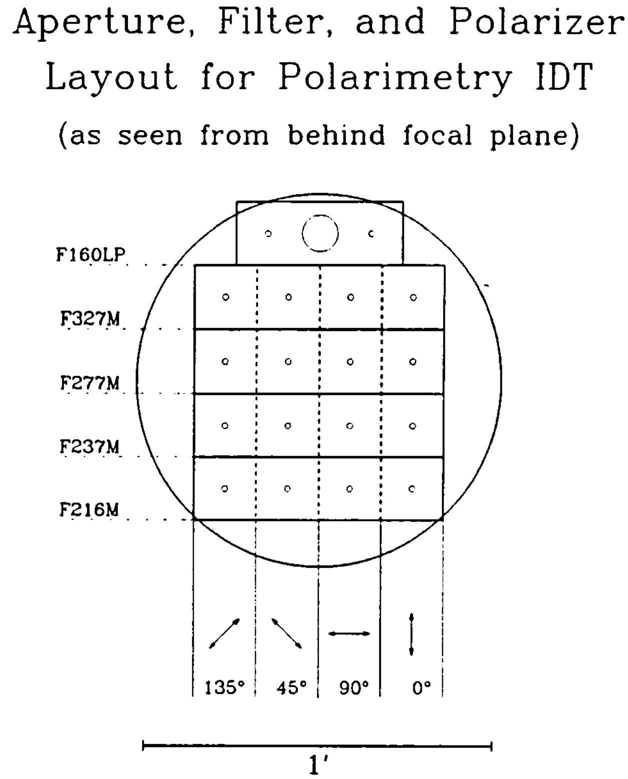

Figure 2–7: *Polarimetry IDT (POL) Apertures and Filters*

2.2.5 Images with the HSP

The light paths for the IMAGE, ACQ, and PEAKUP modes are identical to those for the other HSP modes. These modes differ from ordinary photometry only because the data is collected in a different sequence. An *Image* (sometimes called an *Area Scan*) is a series of integrations in which the IDT beam is moved to cover a rectangular grid on the photocathode. The number of x and y points, the separations of the rows and columns, and the sample time at each point are all adjustable. The number of samples taken at each point in the image and the delay time between samples are also adjustable using optional parameters on the Phase II observing forms.

Targets are located in the 10 arcsec finding aperture by commanding the HSP to take an image covering the aperture (§2.5.1). Images will not often be used by observers except for target acquisition, in which case the instrument mode can be specified as ACQ, and all parameters except the exposure time are set to default values. However, HSP images may also have some other uses; *e.g.*, an image could be taken after a target acquisiton to confirm the success of the acquisition.

The PEAKUP mode can be used to center the IDT beam on the target when trying to do very accurate photometry (§3.3.3). As this handbook is being written, this mode is not fully supported in the ground system; astronomers who think they need it should contact the author to find out its current status.

An image may be acquired using any of the IDTs, including the polarimeter. There is an overhead of about 25 ms per point in the image, so that a 20 × 20 target acquisition scan requires at least 10 s. This overhead time is not included when specifying the exposure time for the image, but is charged to the observer.

2.3 Electronics

Figure 2-8 shows a block diagram of the HSP electronics. All five detectors have identical electronic subsystems with the exception of the photomultiplier, which does not have the amplifiers needed in the image dissectors to drive focus and deflection coils. The x and y deflections and focus settings are 12-bit programmable quantities. A change of 1 in the deflection corresponds to a beam motion of about 4 μm (0.02 arcsec). The high voltage power supplies are 8-bit programmable to provide negative DC voltages between 1400 and 2600 volts for the detectors.

The settings of all internal HSP quantities will usually be handled automatically by STScI, although there may be rare observations that require changing the high voltage, discriminator settings, etc., to get the best performance from the HSP.

The output of the detectors can be measured by counting pulses, by measuring the photocurrent, or by doing both simultaneously. In the current (analog) data format*, a current-to-voltage converter measures detector current outputs over a range of 1 nA to 10 μA full scale in 5 decade gain settings selectable by discrete command inputs. The amplifier output is converted to a 12-bit digital value by an A/D converter. The analog data format will be used for stars that are too bright for the pulse-counting data formats. One benefit of the programmability of the high voltage is that it provides a means of extending the dynamic range of the detectors in their analog data format. The minimum sample time in the analog data format is set by the analog-to-digital conversion time of 128 μs. The true time resolution in analog data format is somewhat larger than this; it is determined by the time constant of the current amplifier, which ranges from 4 ms in the 1 nA range to 0.4 ms in the 10 μA range.

It should be emphasized that the effective integration time when collecting data with the analog format is always very short. For example even if the sample time is specified to be 1 sec, the effective integration time is only ~1 ms. Thus, decreasing the sampling rate leads to widely spaced, short samples of the brightness of the star, but does not increase the accuracy of measurement for each sample. The number of samples required to achieve a specified accuracy using the analog format is essentially independent of the sample time (and may be very large for faint objects).

In the pulse-counting (digital) data format, the output of the preamplifiers, which provide a voltage gain of about 7, is received by pulse amplifier/discriminators (PADs). The PADs amplify and detect pulses above a threshold set by an 8-bit binary control input, enabling the signal-to-noise ratio to be optimized for any high voltage setting. The PAD thresholds are usually set by STScI and will rarely be of concern to the observer. Digital format data can be taken with sample times as short as 10.8 μs. Pulses separated by about 40 ns or more can be separately detected so that count rates of up to 2.5×10^5 Hz can be accommodated with a dead-time correction of no more than one percent.

The sample times for both digital and analog data formats are commandable in 1 μs intervals up to 16.384 s. Between successive samples there can be a delay time of zero to ~16 s, again in 1 μs steps. This delay time will usually be set to zero except in cases where a delay is necessary for some reason (*e.g.*, in 1-detector `STAR-SKY` mode, see below). Use optional parameters `SAMPLE-TIME` and `DELAY-TIME` to specify these values on the exposure logsheet. By default the sample time is 1 second and the delay time is its minimum possible value.

The five identical detector controllers perform those functions that relate to a specific detector, *i.e.*, they receive a sequence of parameters and instructions from the system controller necessary for an observation and science data collection. Each contains an I/O port, a storage latch, two 24-bit pulse counters, and a multiplexer. Detector parameters are received from the system controller through the I/O port and are stored in eight one-byte latches. These latch outputs are used to control focus and deflection amplifiers, high voltage power supplies, discriminator thresholds, analog gain settings, etc. A 1.024 MHz clock signal, received through the I/O port, supplies a signal to the A/D converter and synchronizes sampling start and stop control signals to the two pulse counters. It can also be used as a test input to the counters. The outputs of the two pulse counters, the A/D

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* For a detailed description of data format selections, see §3.1.2.

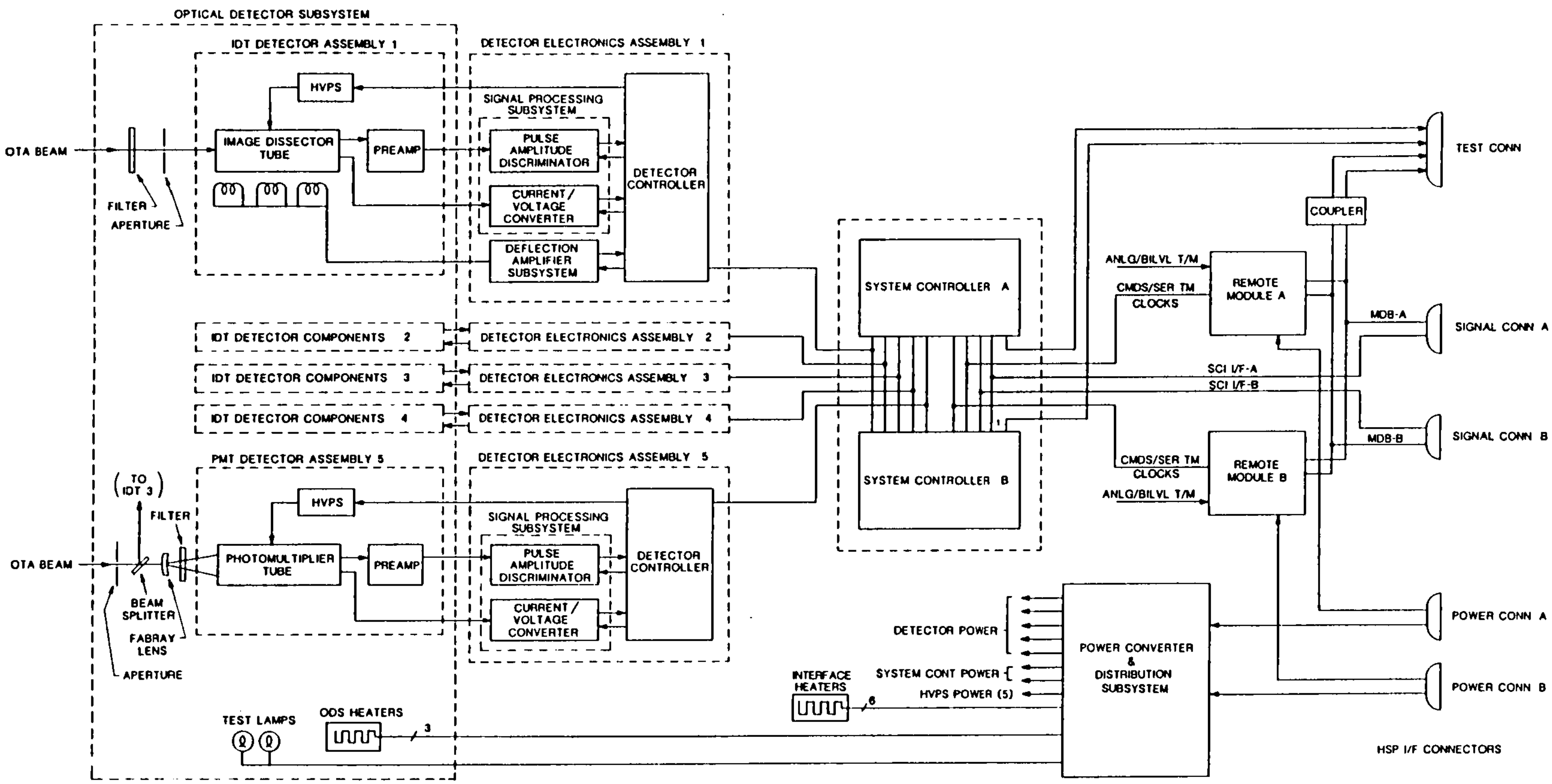

Figure 2–8: *HSP Electronics Block Diagram*

converter, and the eight one-byte latches are multiplexed and transmitted through the detector controller bus I/O port to the system controller.

As its name implies, the system controller's functions have to do with the instrument as a whole rather than with a specific detector. These functions include serial command decoding and distribution, detector controller programming, science data acquisition and formatting, serial digital engineering data acquisition and formatting, and interfacing with the ST command and data handling system through redundant remote modules and redundant science data interfaces. The system controller consists of an Intel 8080 microprocessor, memory, and various I/O ports. Direct memory access is provided to allow rapid data transfer through the science and engineering data ports and to allow science data acquired from the detector controllers to be stored in memory quickly. An 8K byte ROM block is provided for the microprocessor program storage. The remaining memory is composed of six 4K blocks of RAM which may be configured in any order. 4K of the RAM are allocated for the microprocessor system, 16K as a buffer for science data storage, and 4K as a spare block. The spare block may be used to replace any other 4K block that becomes defective. In contrast to the detector controllers, the system controller is dual standby redundant.

The power converter and distribution system converts the input +28V DC bus power from the ST to secondary DC outputs required by all other subsystems and provides power input switching and load switching for independent operation of individual detector electronics and heaters. The DC-DC converters essential to overall instrument operation are dual standby redundant. Converters that power electronics associated with only one detector are not redundant. With three detectors and their electronics on simultaneously the power consumption is about 135 W.

2.4 *Mechanical Structure and Thermal Characteristics*

The HSP is aligned and supported in the ST at three registration points. Two of these (one forward and one aft) have ball-in-socket fittings, and the third point (in the forward bulkhead) provides tangential (rotational) restraint. The mechanical loads (including a pre-load to keep the HSP in alignment) are transmitted from the instrument to the telescope structure through the three registration points. The two ball-in-socket fittings, the electronics boxes, and the optical and detector system are all mounted directly to a box beam and baseplate, the main structural elements of the HSP. The box beam runs the length of the instrument thereby connecting the two forward and aft fittings and carries the pre-load. The baseplate (actually a milled-out lattice structure) is attached to the box beam and provides stiffness to the structure. Four internal bulkheads on each side of the box-beam and baseplate form ten bays for the electronic boxes, which are mounted on the baseplate. In addition to giving mechanical support to the electronics and to the wire harness, the baseplate provides a high conductance path between electronic modules as well as a radiating surface. The optics and detectors are mounted to (but thermally isolated from) the box-beam on the side opposite the baseplate, and at the forward end of the instrument.

Detectors are not actively cooled and are expected to range in temperature between −15°C and 0°C for "cold" and "hot" orbits, respectively. Over an orbit their temperatures will change by no more than 0.1°C. One consequence of the changing temperatures is that the HSP flexes slightly, causing the images of apertures to move on the faceplates of those IDTs that have relay mirrors (*i.e.*, for all the IDTs except the polarimeter). The image motion is about 1 arcsec over the entire temperature range. It is anticipated that the STScI will be able to compensate for this motion so that it will not ordinarily be of concern to the observer.

2.5 *Observing with the HSP*

2.5.1 *Target Acquisition*

An observation with the HSP begins with the acquisition of the target. As for most of the other ST instruments, the HSP has 4 target acquisition strategies: *Blind*, *Onboard*, *Interactive*, and *Early*. These schemes are described in detail in the *HSP Target Acquisition Handbook*; this section briefly summarizes that document.

In a *Blind* target acquisition, the target is put directly in the desired 1.0 or 0.4 arcsec aperture. This is equivalent to doing no acquisition at all. However, it usually will be necessary to determine the target position before going to a small aperture. Neither the target position nor the guide star positions will generally be known accurately enough for a Blind acquisition except when the target has been observed previously.

For the other target acquisition methods, the ST will acquire guide stars in such a way that the program star falls within the large finding aperture of the specified image dissector. The finding aperture has a diameter of 10 arcsec for the photometry IDTs and 6 arcsec for the polarimetry IDT. Nominal guide star and target positions should be accurate enough that the target will never fall outside the finding aperture. A 20×20 raster scan covering the finding aperture is then performed by the dissector to form a pseudo-image (the *Acquisition* image). Acquisitions are requested on the proposal forms with the `ACQ` mode and must be listed as separate exposures on the exposure logsheet. The type of acquisition must be specified using the `ONBOARD` (or `INTERACTIVE` or `EARLY`) `ACQ FOR` ⟨*lines*⟩ special requirement. Typical times required to collect the target acquisition image are given in Table 4-7.

If the star field is simple so that the program star is easily identifiable, the target may be suitable for an *Onboard* target acquisition. Software in the ST computer examines the pseudo-image and makes a list of up to 20 objects within a specified brightness range. The program star can be specified to be the only candidate on the list (in which case it is an error if there is more than one candidate) or the n-th brightest star on the list, where n is 1, 2, etc. The centroid location of the selected star is then found automatically and the correct telescope offset to the desired filter-aperture is calculated. This offset is passed to the ST pointing control system and the small maneuver is carried out. The program star is now in the correct aperture with the detector parameters properly set, and the observation begins.

If the program star is in a crowded field or is highly variable, it may not be possible to acquire it by means of the automatic finding routine described above. Instead, an *Interactive* or *Early* target acquisition is necessary. In an *Interactive* acquisition, the psuedo-image is displayed on the ground where the observer indicates the program object with a cursor; then its position is transmitted to ST. Obviously the observer must be present at the STScI if an Interactive acquisition is necessary. At most 20% of all observations will be allowed to have Interactive target acquisitions because of limitations in communication links with the satellite.

In many cases the target acquisition image can be taken in advance of the actual observation (an *Early* acquisition), making real-time interaction with ST unnecessary. This avoids both the necessity that the observer be present for the observations and difficulties with real-time interactions with ST. Early acquisitions may also make use of the imaging instruments onboard ST, the WF/PC and the FOC.* If the field is very complicated, the target faint, or the target's ultraviolet magnitude very uncertain, then it may prove useful (or necessary) to get a Wide Field Camera image of the field before the HSP observation. The pointing requirements for target acquisition by the WF/PC are obviously much less stringent than those of the HSP. Unfortunately, the long slews required to move a target from the WF/PC to the HSP will often preclude the use of the same guide stars for the two instruments; this will mean that it will still be necessary to perform some sort of target acquisition with the HSP before observing the target, though it may be possible to use a nearby star which is suitable for an Onboard acquisition. See the *Target Acquisition Handbooks* for the HSP and the other instruments for more information on various strategies for difficult cases.

* The FOC will not be used as often as the WF/PC because its field of view is only twice the diameter of the HSP finding apertures.

For faint objects ($m_V > 20$, depending on the color of the star), the time to acquire a 20×20 HSP image may become prohibitive. Then it becomes necessary to adopt a somewhat different target acquisition strategy. There are several possibilities:

(1) Use the WF/PC (discussed above).
(2) Reduce the size of the HSP image. For example, a 10×10 image will still usually be large enough to include the target, but requires only 1/4 the time of a 20×20 image.
(3) Choose a brighter star nearby for offset pointing. For offset target acquisition, the bright offset star is acquired (using any of the usual techniques, including Onboard acquisition); then the telescope is slewed to place the position corresponding to the real target in the desired aperture.

The brightness of the target and the availability of offset stars will determine which of these techniques will be best for a particular object.

Proper motion and parallax of the target will be removed in the process of the target acquisition for Onboard and Interactive acquisitions. They will be important only for: (1) solar system targets that are moving rapidly, (2) Blind acquisitions in which the target either has not been previously observed or in which the target has moved significantly since the last observation, or (3) targets acquired via offset pointing. In any case, target motions of less than about 0.1 arcsec during the course of a series of exposures are not important for HSP observations.

2.5.2 *Sky Subtraction Modes*

If a measurement of the sky background is required, it usually can be made through one of the three other apertures corresponding to the same filter. Apertures in a given row are 7.5 arcsec apart (and apertures of the same diameter are 15 arcsec apart) so generally one aperture should be suitably located for a background measurement. The ST pointing need not be changed; the dissector simply is commanded to collect photoelectrons from the point on the photocathode corresponding to the selected sky aperture. This section discusses the various operating modes that can be used for sky subtraction with the HSP. See §2.2 for a list of which modes can be used with the various HSP configurations. The *HST Phase II Proposal Instructions* give the precise format that must be used.

The HSP will most commonly be used in `SINGLE` mode, in which an exposure consists of a series of measurements of the star's brightness made through some filter/aperture combination. Multi-color photometry is simply a series of `SINGLE` exposures. Measurements of the sky brightness can also be made as `SINGLE` exposures (requiring a separate line on the Exposure Logsheet).

If the background brightness is expected to vary significantly during the exposure, then the HSP can be commanded to measure alternately the star brightness and the sky brightness from 2 different apertures on the same IDT (`STAR-SKY` mode). For `STAR-SKY` mode, the sample times for the star and the sky can be set independently (using the `SAMPLE-TIME` and `SKY-SAMPLE` optional parameters).

The minimum time required for the image dissector beam to be deflected from one location to another is 10 milliseconds. Should measurements of the star's brightness be required at intervals shorter than that, two alternatives are available: either background exposures can be taken before and after the high speed data run (requiring 3 `SINGLE` mode exposures, 2 on the sky and 1 on the star), or if a second dissector contains a filter identical with or relatable to the filter used for the program star, two dissectors can collect data simultaneously, one from the star, one from the sky (also `STAR-SKY` mode, but with the two different detectors specified in the configuration as `HSP/`$\langle D_1 \rangle$`/`$\langle D_2 \rangle$). In this mode, the sample times for each detector must be identical but can be as short as 28 μs. This is slightly more than twice the shortest possible sample time (10.8 μs) when only one detector is collecting data. In principle this sample time could be reduced by using a special "bus director" program (see §3.1.1).

The SPLIT configuration, in which a beamsplitter sends part of a star's light to two different detectors, uses the same technique as two-detector STAR-SKY mode to get simultaneous measurements of a star in two colors. On the other hand, two-color photometry using the PRISM mode is accomplished using the equivalent of one-detector STAR-SKY mode, switching the beam of a single IDT between the two apertures associated with a particular prism. Thus, prism mode measurements are not truly simultaneous but are separated by at least 10 milliseconds, just as are all one-detector STAR-SKY measurements.

2.5.3 Occultation Observations with the HSP

The HSP has many advantages over ground-based telescopes for occultation observations:

(1) Shorter sample times allow greater resolution.
(2) UV observations and smaller apertures greatly reduce the scattered light from the occulting body.
(3) "Stationary" occultations occur when the motion of ST nearly compensates for the motion of the occulting body.

The most difficult part of planning an occultation observation is probably calculating which occultations are favorable for observations with the ST. After launch, the STScI will supply orbital elements to those who would like to do occultation predictions; however, STScI will not be able to do such predictions for GOs. Another difficulty is that atmospheric drag causes the orbit to change on relatively short timescales, making it difficult to predict the location of ST accurately more than a short time (about a month) in advance. This means that it will often be impossible to determine at the time of proposal whether the ST will be suitably placed to observe a particular candidate occultation. As a result, many occultation observations will have to be proposed as targets of opportunity.

2.5.4 Other Useful Information

The 10^5 Hz data collection rate (in which a data word is 8 bits long rather than the usual 16) would fill the HSP buffers in only 0.16 s. However, data at this rate can be transferred continuously to the on-board tape recorder for about 10 minutes, where it will be stored until its contents are transmitted to the ground. More details on the transmission and storage of data are given in Chapter 3.

Most observations will be made by commands stored on-board the ST. About 20% of the time, however, it is expected that it will be possible to make interactive observations in real time. This will be useful in many circumstances. One example is the interactive target acquisition described above. Also, in real time one could change an amplifier gain or command a move to another filter-aperture combination should it be desirable to do so. Of greatest interest, perhaps, is the possibility of moving to another target star if, for example, the first one was in a quiescent rather than an active phase. In any case, all such changes must be checked by STScI beforehand to insure that no spacecraft constraints are violated by any of the possible program options. There may also be other restrictions; for example, it may be possible to have only one branching point for each observing sequence. Despite these restrictions, the ability to do interactive observations should be of considerable use to HSP users interested in observing flare stars, etc. See the *Call for Proposals* and the *Proposal Instructions* for further information about interactive observations.

The HSP contains no calibration lamps; its final radiometric calibration will be established by observing stars with known spectral energy distributions. The instrument's sensitivity can be estimated from the specification that in 2000 s it be able to measure a 24^{m} star in the B band with a signal-to-noise ratio of 10. Typical image dissector dark counts and currents are less than 0.1/sec and 1 pA, respectively. Chapter 4 gives a detailed description of the HSP sensitivity.

Chapter 3: Details of the HSP-ST System

Chapter 2 describes the general characteristics of the HSP in enough detail for most observing programs. However, sometimes more information will be needed in order to use the HSP as efficiently as possible. This chapter has sections on some internal details of the HSP's operation, on some quirks and limitations of the HSP-ST system, and on sources of noise in measurements made with the HSP.

3.1 Internal Details of the HSP

3.1.1 The Bus Director

Individual observing sequences in the HSP are carried out by a "nanoprocessor" called the Bus Director (BD). The BD executes a very limited set of 16 instructions which do things like load the latches of a particular detector with deflection settings, cause the contents of a counter or an A/D converter to be placed into the science data buffer, loop a specified number of times, or wait a specified number of clock cycles. (One clock cycle is 1/(1.024 MHz); for convenience this usually is referred to as 1 tick.) Thus, a sequence of 100 1 sec samples on a star is executed by a BD program that loops 100 times through instructions which start a counter, wait 1 sec, then stop the counter and put its contents in the science data buffer. All of the different data formats and modes that are described below are the result of "standard" BD programs; however, it is also possible to write non-standard programs to produce new modes or formats (*e.g.*, a Star/Sky/Dark sequence which measures the dark counting rate separately from the sky background rate, or a data format in which only the *top* 2 bytes of the 3 byte digital counter are read out.) It is far beyond the scope of this manual to give enough information for the reader to write his or her own BD programs; contact STScI for more information if you have an observation that requires a new BD program.

3.1.2 Standard Data Formats

There are five standard data formats (and a default) for HSP data. They are:

Table 3–1: *HSP Data Formats*

Format	*Description*	*Restrictions*
BYTE	1 byte digital	$Ct < 256$ cts, $C <\sim 2 \times 10^6$ cts/s
WORD	2 byte digital	$Ct < 65,536$ cts, $C <\sim 2 \times 10^6$ cts/s
LONGWORD	3 byte digital	$Ct < 16,777,216$ cts, $C <\sim 2 \times 10^6$ cts/s
ANALOG	12 bit analog (in 2 bytes)	$C >\sim 10^5$ cts/s
ALL	3 byte digital plus 2 byte analog	$C >\sim 10^5$ cts/s
DEF	Default: Format selected by STScI	

Here C is the count rate from the target and t is the sample time for the observation (specified by optional parameter SAMPLE-TIME). Chapter 2 distinguishes only between digital and analog data formats because it will often be unnecessary for the observer to specify which particular format is to be used. In that case the sixth entry in the table, DEF, is selected (by default) on the observing forms; then the data format is set to the STScI default for the source's counting rate (as specified by the flux data in the target list) and integration time. The brightness of the source determines whether pulses can be counted or whether the IDT current must be measured; if the count rate is low enough for pulse-counting, the sample time determines whether 1, 2, or 3 bytes of digital output will be necessary. The shorter digital formats (BYTE and WORD) are used to reduce the data rate out of the HSP when the sample time is short. Except in a few ambiguous cases, the STScI should be able to determine which data format is best for a particular observation. If necessary, the data format can by specified on the observing form using the optional DATA-FORMAT parameter.

Note that the ALL format allows the simultaneous measurement of the IDT output using the pulse-counting and current methods. This is useful for cross-calibration of the 2 techniques and for observing bright stars with count rates near the limit of the pulse-counting modes (typically between 10^5 and 2×10^6 cts/s).

Any data format may be used with any observing mode, though only the WORD and ANALOG formats are permitted for onboard target acquisitions.

3.2 The HSP-ST System

This section describes aspects of the interaction of the HSP and the ST, some of which are obvious and some of which are quite subtle.

3.2.1 Changing Filters with the HSP

The HSP's filter/aperture "mechanism" requires the ST to execute small slews to move the target from one filter to another. This means that the time to change filters is determined by the time for ST to do a small angle maneuver, which turns out to be about 30 seconds for all slews shorter than 1 arcminute. (This may seem surprisingly long; it is necessary to move slowly to avoid setting up long-lived oscillations in ST's solar panels.) Consequently, when doing multicolor photometry with the HSP, it is inefficient to integrate less than ~30 seconds between filter changes, because then most of the ST time will be spent slewing from filter to filter instead of collecting photons.

For 2 filters on different IDTs, the slew time is about 60 seconds, so the exposure times through each filter must be even longer for efficient use of ST time.

If a program requires multicolor observations at shorter intervals, a pair of filters that is accessible through one of the beamsplitters must be used (Table 4-3).

3.2.2 Limits to the Length of Uninterrupted Observations

It will often be difficult or impossible to acquire an uninterrupted series of integrations lasting more than about 30 minutes. The *Call for Proposals* discusses ST's orbital constraints. The ST will be in a low orbit so that almost half of the sky is occulted by the earth. Thus, most objects will be unobservable for about half of each orbit, and each orbit requires only 95 minutes. Furthermore, it will not be possible to point ST closer than 50° from the sun, and the sky background will be high when looking at a target close to the earth's bright limb.

Data are transmitted from ST to the ground or stored on the onboard tape recorder at either 4×10^3 or 1.024×10^6 bits/sec (4 kbs or 1 Mbs). There is also an internal 32 kbs link to the tape recorder. The data rate from the HSP, R, is determined by the sample time, t, and the number of bits per sample, n: $R = n/t$. The data rate from ST to the ground is always at least 14% larger than this because of data added by the spacecraft computer (*e.g.*, error correction bits). The bandwidth available to the HSP is reduced even more if other ST instruments are being used at the same time, as will often be the case.

There are various restrictions that arise for the three different link rates. When the HSP is producing data more slowly than 4 kbs, the data rate generally places no restrictions on the total length of the observation time. If the 1 Mbs link is required, then the length of the observation will be limited to the tape recorder capacity (about 10 minutes of continuous data) or to the duration of the 1 Mbs downlink (~20 minutes on the average). Between 4 kbs and 32 kbs the length of the observation may also be limited: if the tape recorder is not available, the data will have to be sent to the ground at 1 Mbs.

To determine whether these restriction are important for a particular observation, you need to know the following information:

(1) Is the target in the continuous viewing zone (CVZ)? Targets in the CVZ are continuously visible for several days during certain phases of ST's 56-day orbital precession. Targets not in the CVZ are occulted by the earth on every orbit.

(2) What is the required data rate? $R \geq 1.14n/t$, where t is the sample time (determined by your scientific objectives) and n is the number of bits per sample (determined from t and from the target count rate C — see Table 3-1.)

   (a) $R \leq 4$ kbs: no limit on observing time.

   (b) $4 \leq R \leq 32$ kbs: observations may be up to 8 hours long if data are stored on onboard tape recorder.

   (c) 32 kbs $\leq R \leq$ 1 Mbs: observations may usually last only 10–20 minutes, depending on the availability of the 1 Mbs TDRSS link to the ground.

All of these restrictions mean that most observations that require more than 20 or 30 minutes will probably have gaps in their time coverage. These gaps will obviously lead to some difficulties in the data analysis (*e.g.*, aliases of the 95 minute orbital period will show up in periodic analyses). Observers should try to anticipate how these problems will affect their projects; if gaps in the data will make it impossible to achieve the goal of the program, they should be sure to ask for continuous observations in the proposal. For some programs it may be necessary to choose targets in the "continuous viewing zones", small regions near the orbital poles that are visible throughout the orbit because they are not occulted by the earth. Note that the continuous viewing zones are always near the limb of the earth, so sky subtraction may be more critical for such observations than for targets far from the limb.

3.2.3 Unequally Spaced Data

Most high speed photometrists are accustomed to using mathematical tools such as fast Fourier transforms and autocorrelation functions to analyze their data; these tools require that the data be equally spaced. However, another consequence of the ST's low orbit is that data from the HSP often will *not* be equally spaced in time. The light travel time from one side of the ST orbit to the other is about 40 msec. Consequently, observations that have sample times shorter than this and that last a significant fraction of an orbit will not be equally spaced in the heliocentric rest frame. The STSDAS system at STScI will provide software to calculate the time of each sample in the solar rest frame; however, the observer should be prepared to analyze the resulting unevenly spaced data.

3.2.4 Absolute Timing of Observations

Although the HSP can make observations with sample times as short as 10.8 μsec, the absolute time of an observation can only be established to within a few milliseconds. This happens because the phase of the ST onboard clock is only known to a few milliseconds compared to the time on the ground. The exact accuracy of the clock will be measured after launch; the specifications require the uncertainty to be less than 10 msec, but it is possible that HSP observations of standard sources (*e.g.*, the Crab pulsar) can establish the ST onboard time with greater accuracy. Proposals that require absolute timing better than 10 msec should not be submitted until after post-launch calibration of the clock has been shown to work.

3.3 Sources of Noise and Systematic Errors

There are many sources of noise and/or possible systematic errors for the HSP. This section discusses those that are currently judged to be of possible significance. Which of these are most important will in many cases not be known until after launch.

3.3.1 Noise

"Noise" is here taken to mean random variations in the measured counting rates that would average to zero in a long series of observations. The noise in most HSP observations will be determined by the Poisson statistics for the star, sky, and detector dark counts. The star counting rate obviously depends on the color and magnitude of the star and on the filter used. The sky counting rate has the same dependencies; it also depends on the angle to the sun, the moon, and the limb of the earth in a complicated and (until launch) unknown way.

Dark counts in the HSP may be produced either by emission of thermal electrons from the photocathode ($\sim$0.1 counts/sec for the IDTs, $\sim$200 counts/sec for the PMT) or by impacts of high energy particles on the photocathode and the first dynode. Large particle fluxes like those encountered in the South Atlantic Anomaly may also cause the MgF_2 in the HSP filters and faceplates to fluoresce for a period of time. The particle background and its effect on the HSP will vary with the position of the ST in its orbit and will have to be determined from post-launch observations.

Very bright sources will have to be measured using analog (current) data format because their counting rates will be too high for the pulse counting electronics. The statistics of noise for the current data format will be determined by the counting rate, the time constant of the current amplifier, and the sample time. The noise will consequently be somewhat more complicated than simple Poisson statistics.

Only when the number of photons counted is very large ($> 10^6$) will other sources of noise become noticeable. One such noise source will be the imperfect guiding of the ST pointing system. Guiding errors move the source away from the center of the aperture, decreasing the fraction of the source's flux that reaches the HSP detector. Spatial variations in the quantum efficiency of the photocathodes may also lead to small variations in the count rate as the image of the star moves. These fluctuations should be quite small ($< 0.1\%$), but will be noticeable if a source is bright enough to be measured to this accuracy in the FGS cycle time of a few seconds.

Fluctuations in the high voltage can change the gain of the photomultiplier sections of the IDTs. This will have little effect on the pulse counting rate, but may change the current out of the tube. The HSP high voltage power supplies have been designed so fluctuations will lead to IDT current variations smaller than 0.1%.

Fluctuations in the low voltages could also affect the performance of the HSP by changing the deflections and focus of the IDTs, the threshold of the pulse amplitude discriminator, the output voltage of the current-to-voltage converter, etc. However, all of these effects have been found to be negligibly small in laboratory testing.

3.3.2 Systematic Errors

The accuracy of the measured brightness will be determined for many sources by systematic errors which do not average to zero after many measurements. The sizes of systematic errors are inherently more difficult to determine from observations than are noise amplitudes; this problem is made even harder by the fact that the HSP is capable of making more accurate measurements than any ground-based photometer; consequently, the systematic errors of the HSP photometric system probably will not be measurable by comparison to observations using other instruments. It is hoped that the sum of all systematic errors that cannot be removed will be less than 0.1% of the signal.

Small-scale spatial variations in the filters and photocathodes will cause errors in the measured fluxes since the calibration targets and program targets may not be placed in exactly the same locations within any given aperture. These errors should not be large because the beam is not in focus at the filters and the photocathodes are quite uniform on small scales. The degree to which target positioning is reproducible depends on the performance of the ST pointing control system, which will not be known until after launch.

Non-linearities in the A/D conversion may limit the accuracy of analog (current) mode measurements. Since the A/D converter has 12 bits, even a perfect device cannot measure the current to an accuracy better than ~0.03%.

Fluctuations from guiding errors, discussed above with reference to noise, can also produce systematic errors. It is likely that the guiding errors will be different for objects with different guide stars. Consequently, two objects with identical fluxes may have different average counting rates: the one with larger guiding errors will appear to have a smaller flux. It may be possible to remove this effect by analyzing the engineering telemetry from the ST to determine how large the guiding errors were for a particular observation.

The IDTs inside the HSP must warm up for some time before they can be used for accurate photometry. This warm-up time will be a function of the accuracy that is desired; for example, a few seconds will probably suffice for 10% photometry. The characteristics of the HSP when it is warming up will not be fully known until after launch.

The changing temperature of the HSP can lead to systematic variations in the counting rate. The photocathode efficiency can vary as a function of temperature; this will be important for the PMT and possibly the bialkali IDTs (VIS and POL), but should not affect the CsTe IDTs (UV1 and UV2) which have photocathodes with much larger work functions. All voltages produced by electronic power supplies will also vary with temperature. Most of these effects will be removed by STScI through calibration observations at different temperatures.

Chapter 2 mentioned that the flexing of the HSP as its temperature changes causes the image of the aperture plate to move slightly on the photocathode. If not entirely compensated, this will result in the target being improperly centered in the aperture, and its flux relative to the calibrator (which presumably was centered correctly) will be incorrectly determined. As soon as the thermal behavior of the HSP-ST system is understood, corrections for the thermal motion of apertures will be incorporated into the ground system; however, this thermal modeling is expected to prove difficult. Mis-centering of targets may be the largest single source of systematic error in HSP measurements.

3.3.3 Reducing Systematic Errors

Many of the systematic errors can be reduced greatly by observing a calibration target before and after observing program targets. The STScI will eventually determine how often such calibration observations must be done to achieve a given level of accuracy. Note, however, that very critical observations probably will always require extra calibrations (which will count as part of your observing time and which must be requested as separate exposures in your proposal.) Chapter 5 describes the standard calibrations that STScI expects to supply for the HSP.

The aperture centering errors can be reduced by using the 1 arcsec diameter apertures rather than the 0.4 arcsec apertures. The smaller apertures should be used only when the background is bright compared to the star, when the field is so crowded that the small aperture is necessary to isolate the target, or when the greatest photometric accuracy is not necessary.

Some centering errors may also be reduced by "peaking up" before the observation. Peaking up may involve both internal HSP operations—such as a small image to center the IDT beam on the aperture—and ST operations—such as a dwell scan to center the target in the HSP aperture. The former ought to be fast, while the latter will be slower. There is onboard software to peak-up the IDT read beam on the aperture which can be accessed using the PEAKUP mode; however, the ground system does not currently support the use of this software, so observers should confer with the STScI before using it in their proposals. Using a dwell scan to center the telescope pointing on the star will require an interactive observation in which the astronomer looks at the data taken at different pointings and identifies which one is the best. This will require a considerable amount of time, but may be useful for long observations in which it is crucial that the target be well-centered.

Chapter 4: Instrument Performance

4.1 Sensitivity of the HSP

This section consists mainly of figures and tables describing the sensitivity of the HSP. Some of the data that are included:

(1) Transmission and/or reflectivity as a function of wavelength for all optical elements: filters, mirrors, polarizers, and beamsplitters.
(2) Tables giving nominal descriptions of all filters (name, central wavelength, FWHM, transmission, etc.)
(3) Quantum efficiency as a function of wavelength and dark count rates for detectors.
(4) Figures giving time to reach S/N 100 for a star of a given magnitude and effective temperature.
(5) Nominal background counting rates through various filters.
(6) The time required for target acquisition as a function of magnitude and color of the target.

Several explanatory comments apply to all the tables and figures:

(1) Filter names are all of the form F*xxxw* where *xxx* is the central wavelength of the filter in nm and *w* is a measure of the width of the filter bandpass with the following approximate ranges:

    $N =$ narrow (FWHM < 5% of central wavelength)
    $M =$ medium (5% < FWHM < 15%)
    $W =$ wide (FWHM > 15%)
    $LP =$ longpass (filter passes all wavelengths longward of *xxx*)

(2) "Throughput" means the peak efficiency for the entire HSP/ST system, including reflectivity of mirrors, filter, polarizer, and beamsplitter transmission, and detector efficiency.
(3) "Transmission" means the peak value for the given optical element (filter, polarizer, *etc.*) alone, not including any other elements in system.

At the end of the chapter is an example that demonstrates how to use the information in the tables and figures to estimate exposure times for HSP observations.

Table 4–1: *HSP Photometry Filters*

Name	λ (Å)	*FWHM* (Å)	*Transmission* (%)	*Throughput* (%)	*Remarks*
F122M	1220	130	7	0.05	
F135W	1350	230	12	0.05	
F145M	1450	200	13	0.10	
F152M	1520	180	13	0.13	
F179M	1790	220	30	0.9	
F184W	1840	370	31	1.0	
F218M	2180	170	35	1.3	
F220W	2200	350	35	1.3	
F240W	2400	550	48	1.6	
F248M	2480	370	35	1.2	
F262M	2620	290	33	1.0	UV2 IDT
				1.3	VIS IDT
F278N	2780	140	33	0.4	
F284M	2840	380	31	0.8	
F320N[1]	3200	160	26	0.7	PMT beamsplitter (VIS)
F355M	3550	310	19	0.6	u
F419N	4190	190	31	1.4	v
F450W	4500	1400	65	2.9	B
F551W	5510	850	38	1.1	V
F620W[2]	6200	1300	–	1.5	R
F750W[2]	7000–9000		–	5.4	PMT beamsplitter (PMT)
F140LP	1400–3000		90	3.2	
F160LP[3]	1600–3000		90	3.2	UV2 IDT
	1600–7000		90	4.2	VIS IDT
	1600–7000		90	4.6	POL IDT
F400LP	4000–7000		90	3.7	

NOTES:

(1) Shape of F320N is determined by band passed by PMT beamsplitter rather than by focal plane filter. Transmission is for beamsplitter bandpass.

(2) Shapes of R filter (F620W) and PMT filter (F750W) are defined by the photocathode efficiency, so transmissions for filters alone are not given.

(3) F160LP occurs on both CsTe and Bialkali IDTs. The red cutoff is determined by the photocathode response in both cases.

(4) Unless listed separately, filters that occur on two or three different IDTs have same throughput on all IDTs.

Table 4–2: *HSP Polarimetry Filters*

Name	λ (Å)	*FWHM* (Å)	*Transmission* (%)	*Throughput* (%)
F216M	2160	300	34	0.09
F237M	2370	280	35	0.17
F277M	2770	340	38	0.4
F327M	3270	410	31	0.3

NOTE: All filters on polarimeter are available with 4 polarizers oriented at 45° intervals. On the observing forms, these are specified as *POL0*, *POL45*, *POL90*, and *POL135*.

Table 4–3: *HSP Beamsplitter Filters*

IDT	*Name*	λ (Å)	*FWHM* (Å)	*Throughput* %
UV1 Prism	F135W	1350	230	0.03
	F248M	2480	370	0.3
UV2 Prism	F145M	1450	200	0.06
	F262M	2620	290	0.2
VIS Prism	F240W	2400	550	1.0
	F551W	5510	850 (V)	0.5
PMT	F320N	3200	100	0.7
	F750W	7500	1600	5.4

Table 4–4: *Locations of HSP Filters*

Filter Name	*IDT Name* *UV1*	*UV2*	*VIS*	*POL*	*Substrate*	*Remarks*
F122M	1	1			MgF_2	Lyman α
F135W	2				MgF_2	
F145M	1	2			MgF_2	
F152M	1	1			Crystal Quartz	
F179M		1			Suprasil	
F184W	1	1	1		Suprasil	
F216M				1	Suprasil	
F218M	1	1			Suprasil	
F220W	1				Suprasil	
F237M				1	Suprasil	
F240W	1		2		Suprasil	
F248M	2	1			Suprasil	
F262M		1	1		Suprasil	
F277M				1	Suprasil	
F278N	1	1			WG 280	
F284M		1			Suprasil	
F327M				1	WG 280	
F355M			1		WG 280	u
F419N			1		GG 395	v
F450W			1		BG 28	B
F551W			2		GG 395	V
F620W			1		RG 610	R (red cutoff from IDT)
F140LP	1	1			Crystal quartz	Clear
F160LP		1	3	1	Suprasil	Clear (PMT window)
F400LP			1		GG 395	Clear
F320N			1			PMT beamsplitter (VIS)
F750W			1		RG 695	PMT beamsplitter (PMT) (red cutoff from PMT)

NOTES: (1) Numbers in IDT columns indicate how many slots are occupied by the filter on that IDT.

(2) Locations are also given in Figures 2-4 through 2-7.

(3) All substrates are 1/16 inch thick.

(4) All substrates are coated to produce multi-layer interference filters except for F450W (B), F620W (R), F750W (PMT), and those indicated to be clear.

(5) For several filters (marked "Cutoff from IDT"), one edge of the wavelength response is determined by the cutoff of the photocathode response.

Table 4–5: *HSP Detectors*

Detector	*Photocathode*	*Dark Count Rate (cts/s)* 0° C.	−15° C.
VIS	Bialkali	0.03	0.01
POL	Bialkali	0.05	0.01
PMT	GaAs	400	200
UV1	CsTe	0.05	
UV2	CsTe	0.1	

Table 4–6: *Sky Background Counting Rates for* 1" *Apertures*

Filter	*Detector*	*Sky (cts/s)*	*Remarks*
F240W	VIS, UV	0.008	(without prism)
F240W	VIS	0.005	(with prism)
F248M	UV	0.004	
F262M	VIS, UV	0.005	
F284M	UV	0.005	
F320N	VIS	0.015	IDT/PMT beamsplitter
F355M	VIS	0.019	u
F419N	VIS	0.044	v
F450W	VIS	0.61	B
F551W	VIS	0.26	V (without prism)
F551W	VIS	0.13	V (with prism)
F620W	VIS	0.63	R
F750W	PMT	2.6	IDT/PMT beamsplitter
F140LP	UV	0.031	Crystal Quartz
F160LP	VIS	2.3	Suprasil
F160LP	POL	0.46	Suprasil
F160LP	UV	0.030	Suprasil
F400LP	VIS	1.9	GG 395

NOTES: (1) The sky brightness is modeled as a dilute 4700 K black body distribution with $m_{5556} = 22.7$ magnitudes per square arcsecond (see *Faint Object Spectrograph Instrument Handbook.*)

(2) Sky counting rates for filters at and near Lyman α (F122M, F135W, F145M) are strongly affected by the geocoronal Lα line, which varies greatly depending on the position in orbit and the viewing angle.

(3) For all other filters not listed, the counting rate from the sky is expected to be smaller than the dark count rate from the detector (≤ 0.002 cts/s for VIS, POL and ≤ 0.006 cts/s for UV1, UV2).

Table 4–7: *Target Acquisition Time (minutes)*

UV1, UV2 IDTs

m_V	*Effective Temperature* 5000 K	10000 K	20000 K	40000 K
15	4	0.4	0.2	0.2
16	10	0.6	0.3	0.2
17	25	1.4	0.4	0.3
18	70	3.5	0.8	0.4
19	–	8	1.6	0.8
20	–	20	4	1.8
21	–	50	10	5
22	–	–	25	11
23	–	–	70	30
24	–	–	–	75

VIS IDT

m_V	*Effective Temperature* 5000 K	10000 K	20000 K	40000 K
15	0.3	0.2	0.2	0.2
16	0.4	0.3	0.2	0.2
17	0.6	0.4	0.3	0.3
18	1.2	0.7	0.4	0.4
19	3	1.6	0.8	0.6
20	9	4	2	1.2
21	30	12	5	3
22	–	40	15	9
23	–	–	50	25
24	–	–	–	–

POL IDT

m_V	*Effective Temperature* 5000 K	10000 K	20000 K	40000 K
15	0.2	0.2	0.2	0.2
16	0.3	0.3	0.2	0.2
17	0.6	0.4	0.3	0.3
18	1.1	0.7	0.4	0.4
19	3	1.4	0.8	0.5
20	7	4	1.7	1.1
21	20	9	4	3
22	60	25	11	7
23	–	90	30	20
24	–	–	–	60

NOTES: (1) Time was calculated for a 20×20 image with a signal-to-noise ratio of 6 for the target, including noise from the sky background and dark counts.
(2) An overhead of 25 ms per point is included (10 s for the 20×20 image).
(3) Times longer than 100 minutes are marked "–".

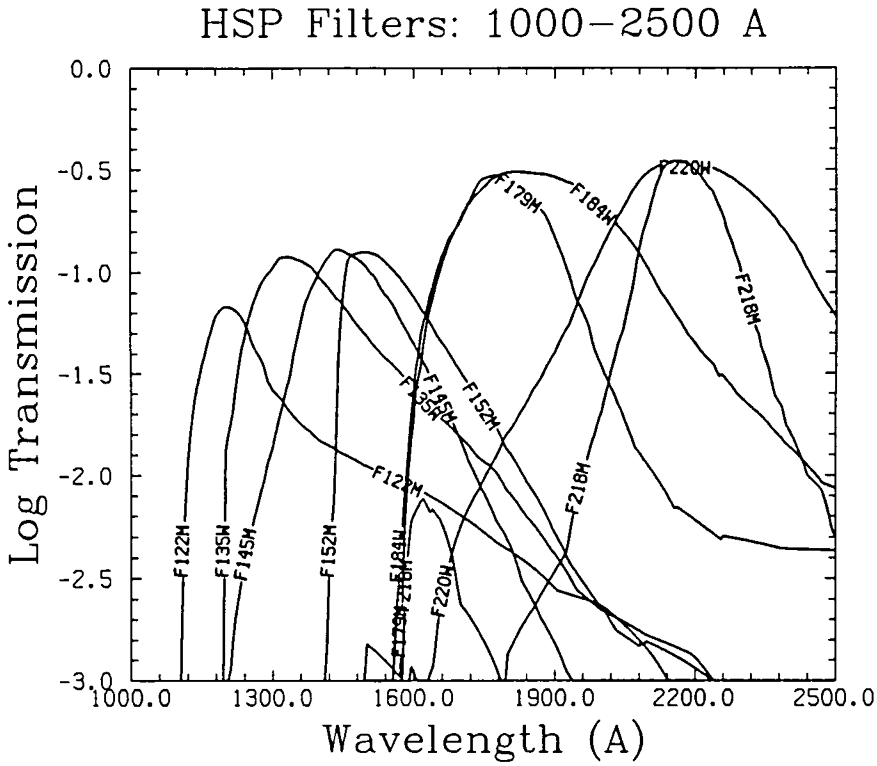

Figure 4–1: *HSP Filters: 1000–2500 Å*

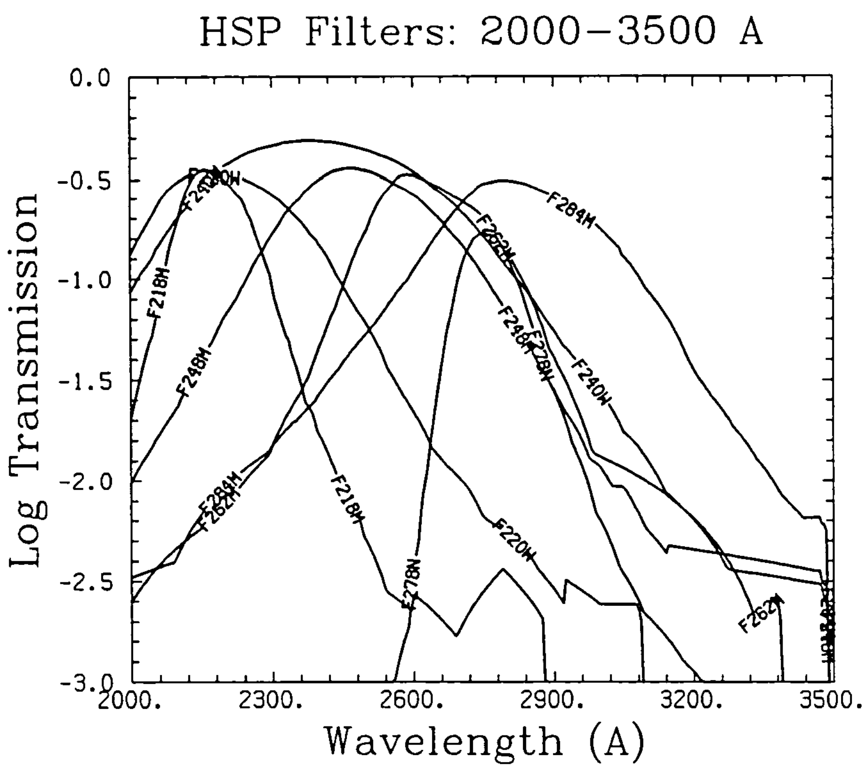

Figure 4–2: *HSP Filters: 2000–3500 Å*

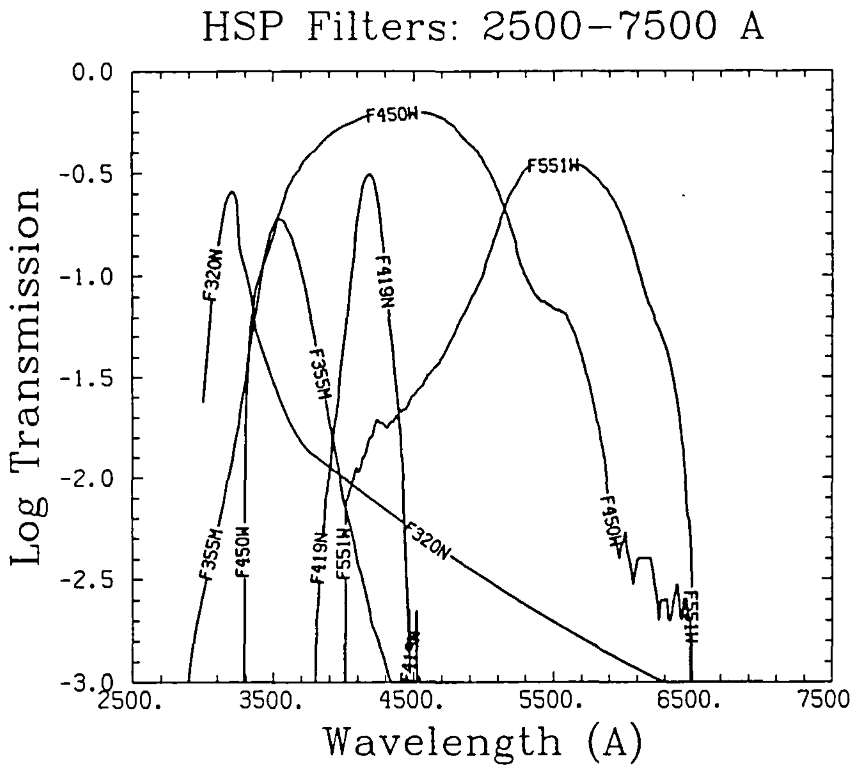

Figure 4–3: *HSP Filters: 2500-7500 Å*

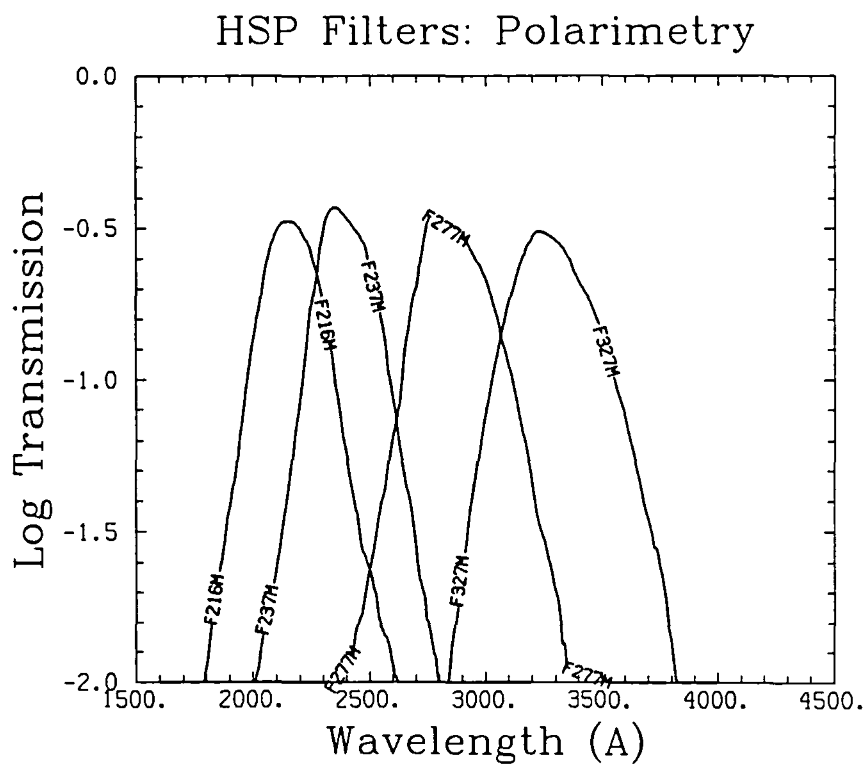

Figure 4–4: *HSP Filters: Polarimetry*

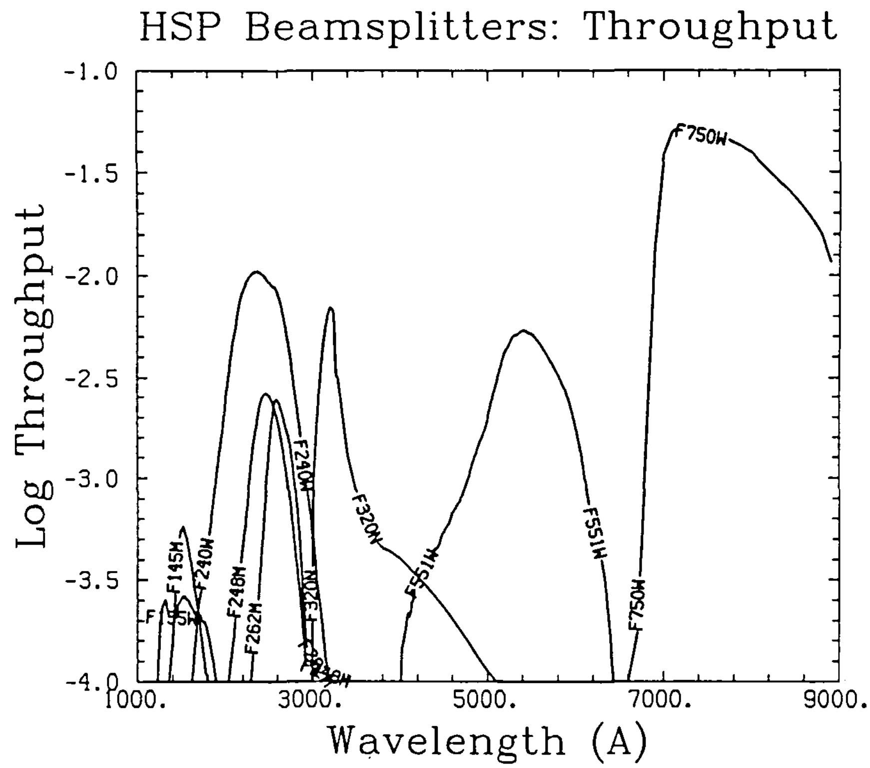

Figure 4–5: *HSP Beamsplitter Filters: Throughput*

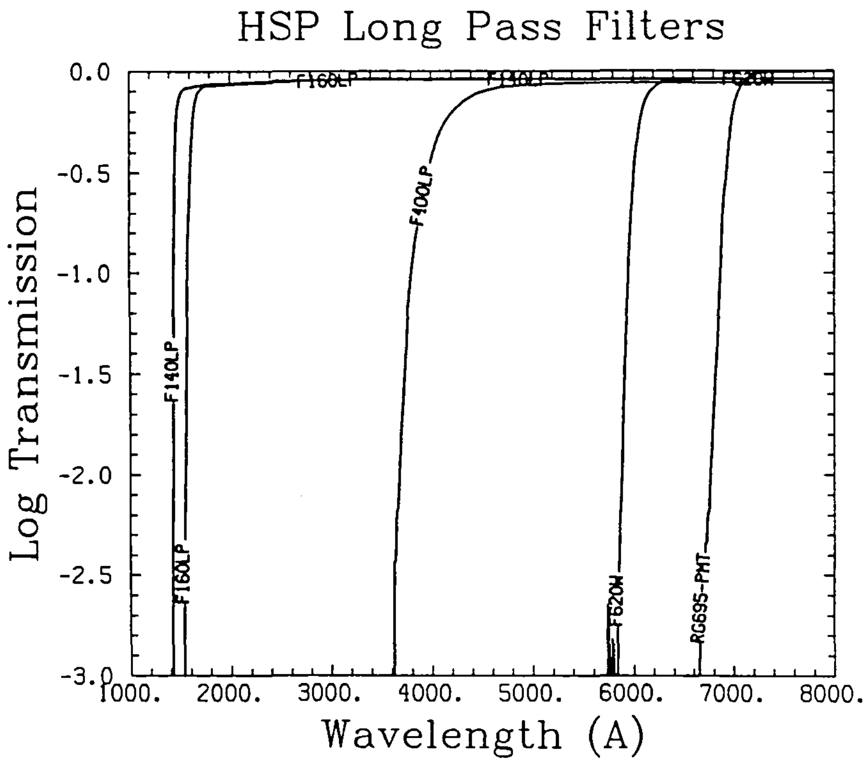

Figure 4–6: *HSP Longpass Filters*

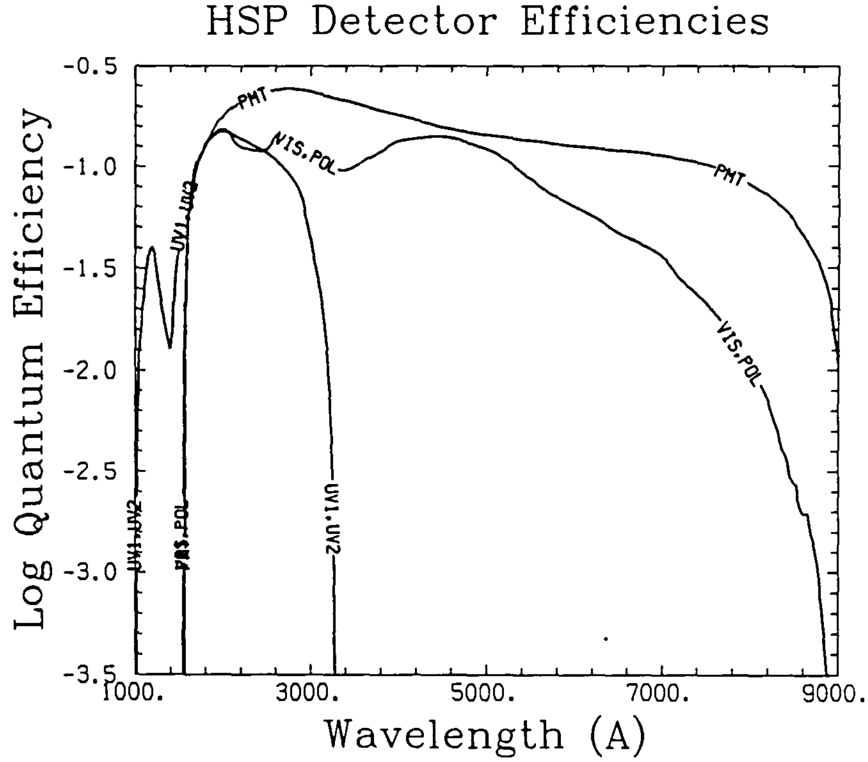

Figure 4–7: *HSP Detector Quantum Efficiencies*

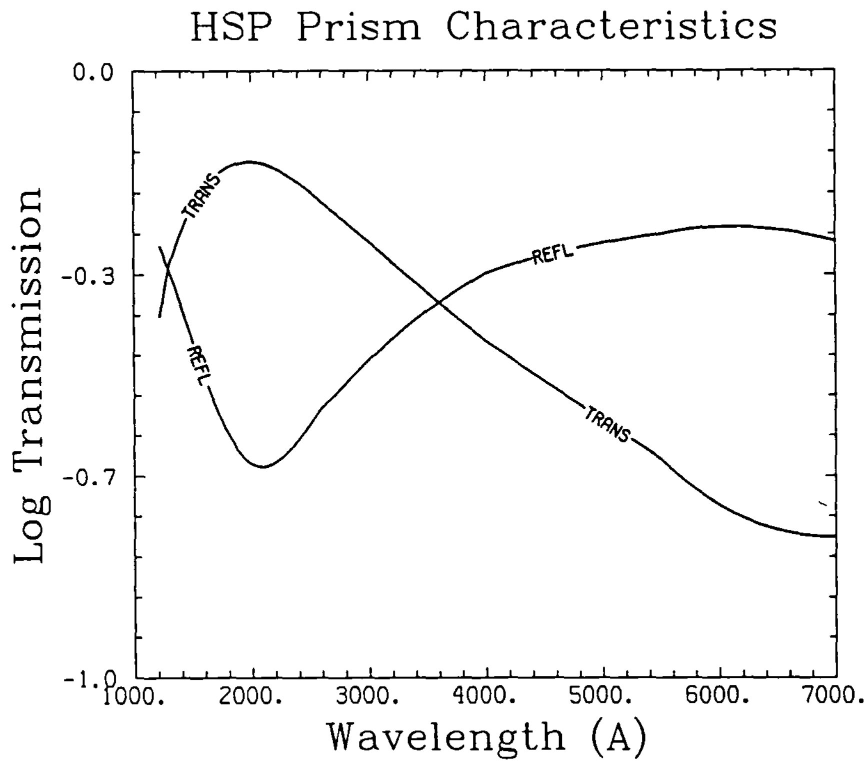

Figure 4–8: *HSP Prism Beamsplitter Characteristics*

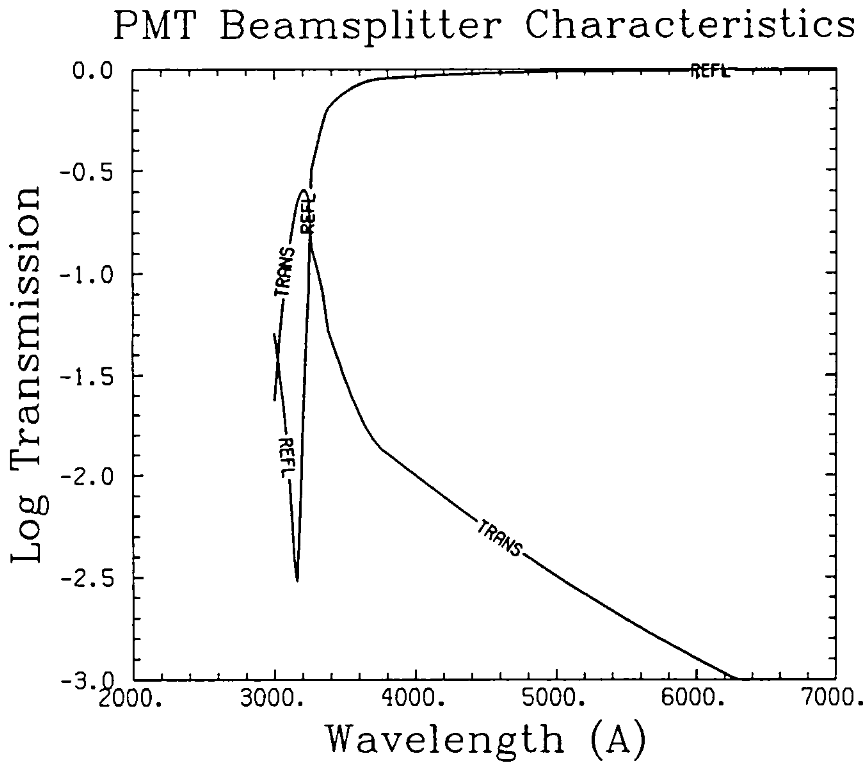

Figure 4–9: *HSP PMT Beamsplitter Characteristics*

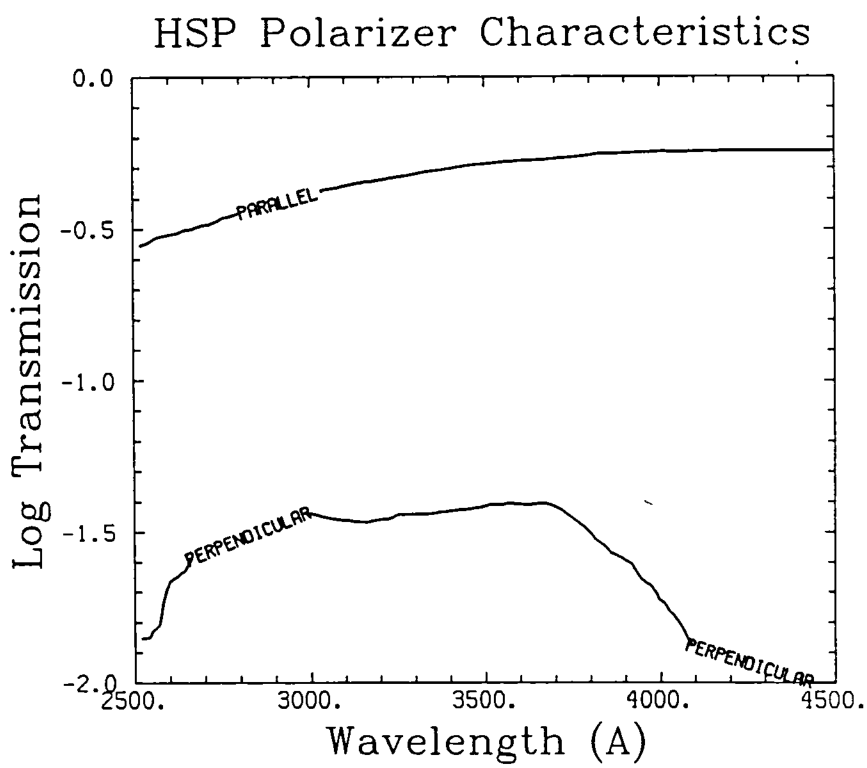

Figure 4–10: *HSP Polarizer Characteristics*

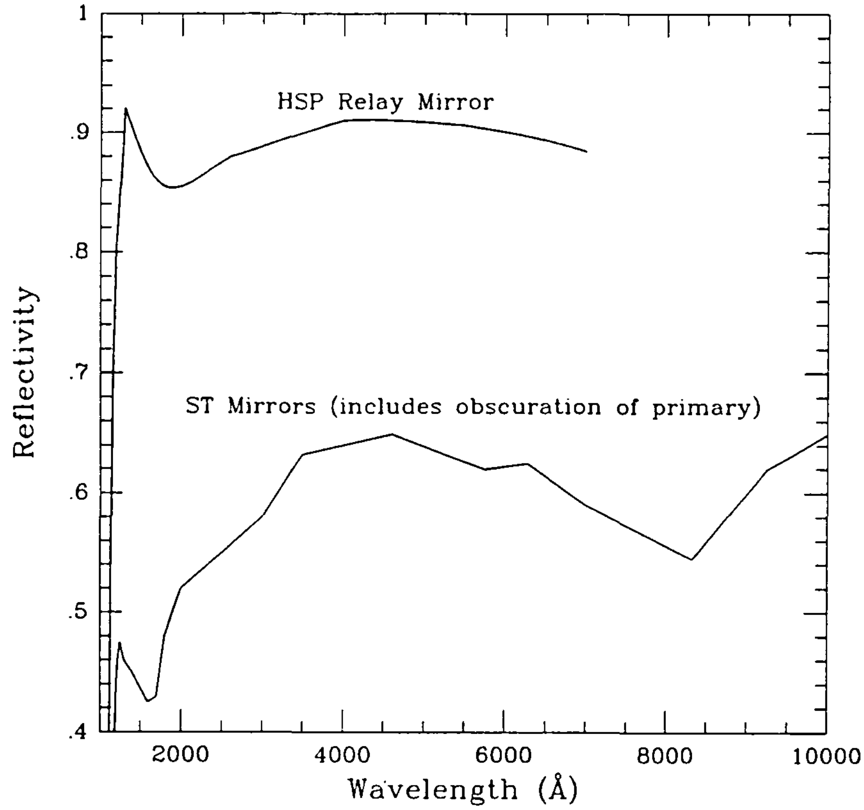

Figure 4–11: *Reflectivity of ST and HSP Mirrors*

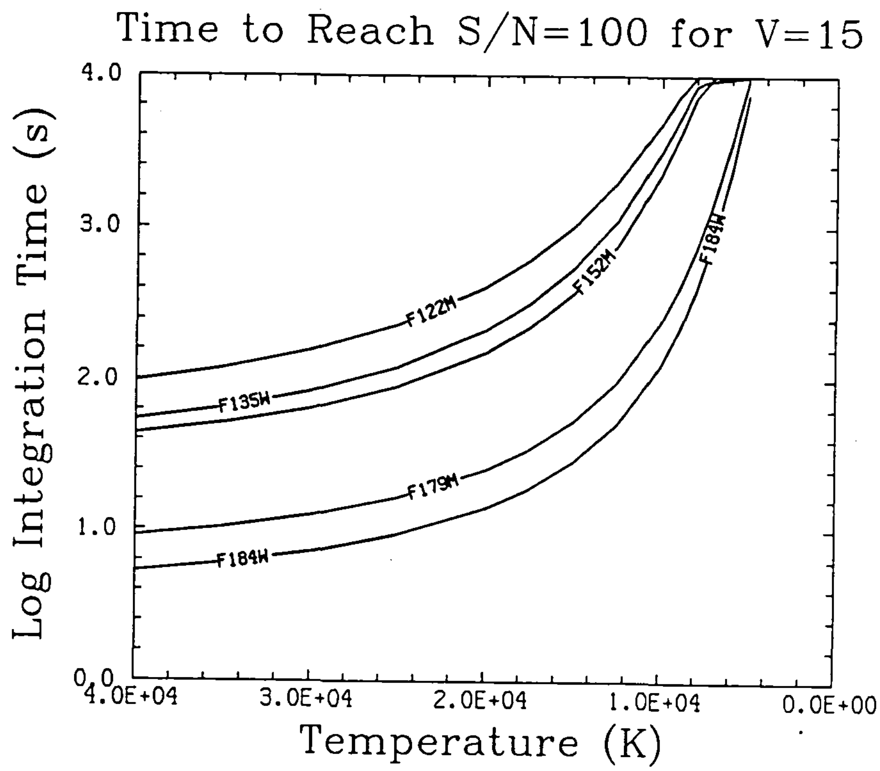

Figure 4–12: *Time to Reach V=15 with S/N=100: UV Filters*

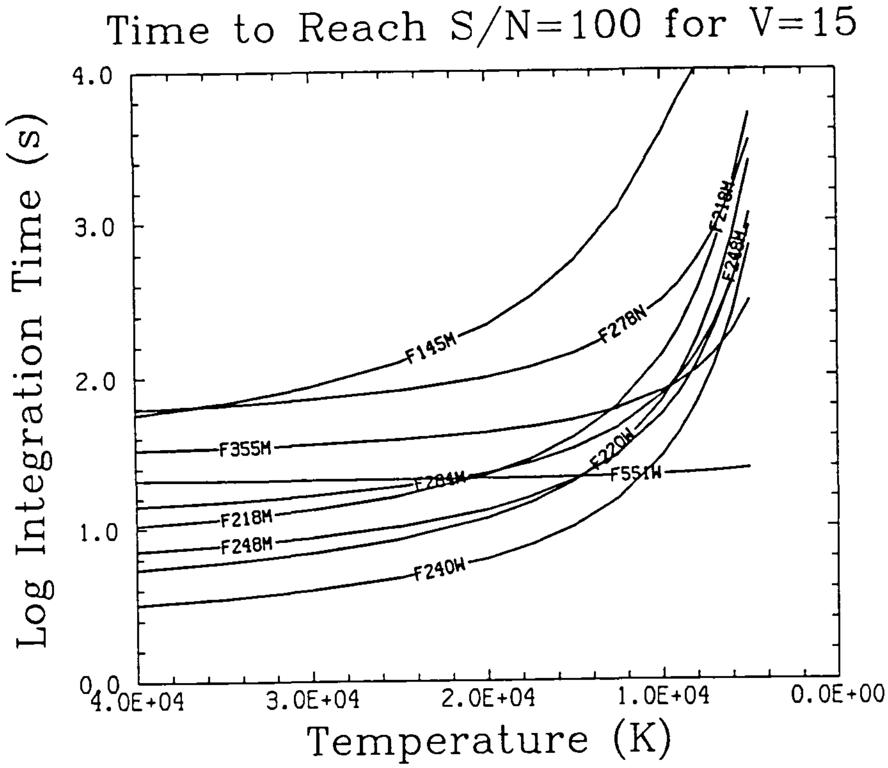

Figure 4–13: *Time to Reach V=15 with S/N=100: UV, VIS Filters 1*

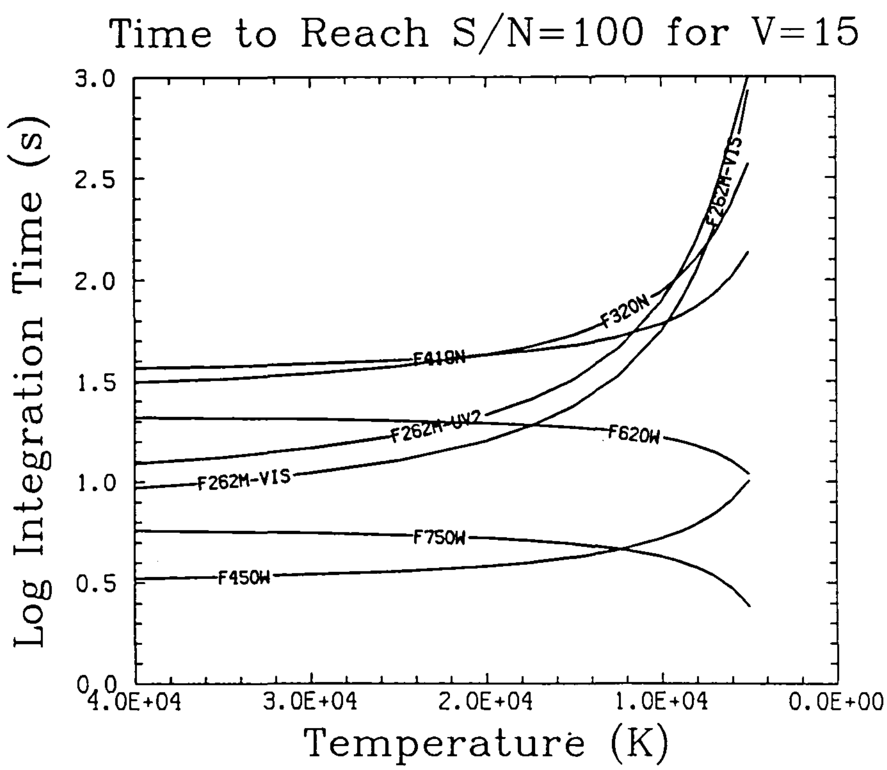

Figure 4–14: *Time to Reach V=15 with S/N=100: UV, VIS Filters 2*

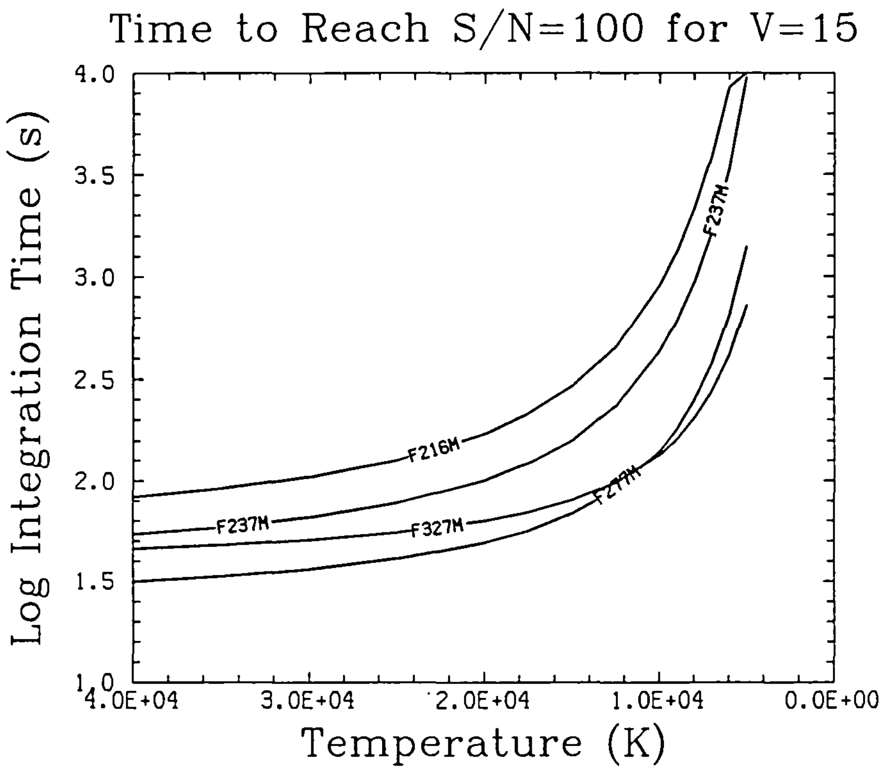

Figure 4–15: *Time to Reach V=15 with S/N=100: Polarimetry Filters*

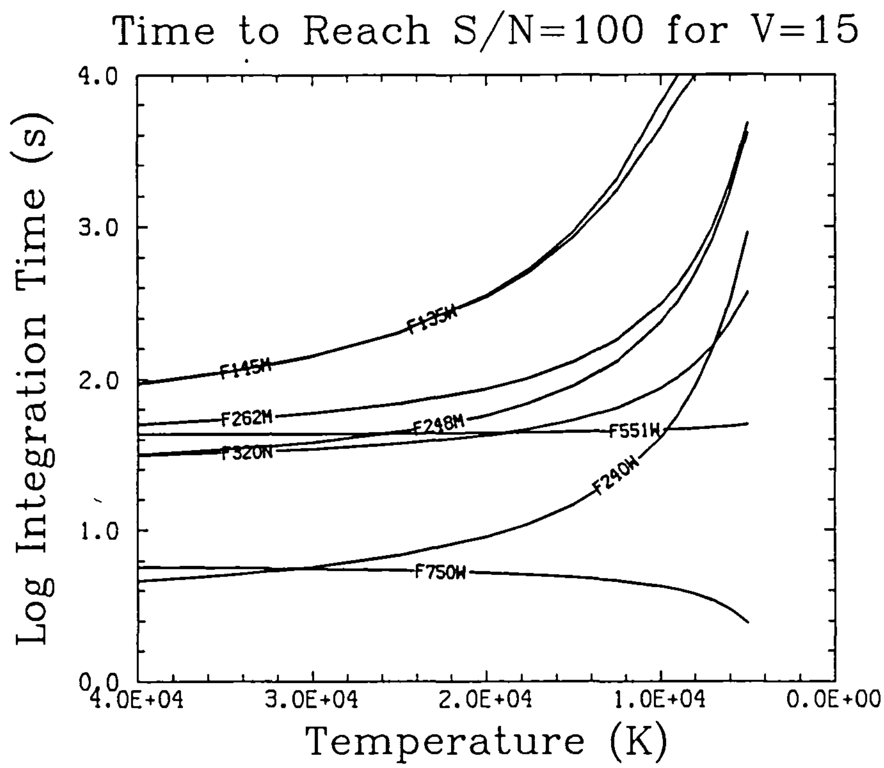

Figure 4–16: *Time to Reach V=15 with S/N=100: Beamsplitter Filters*

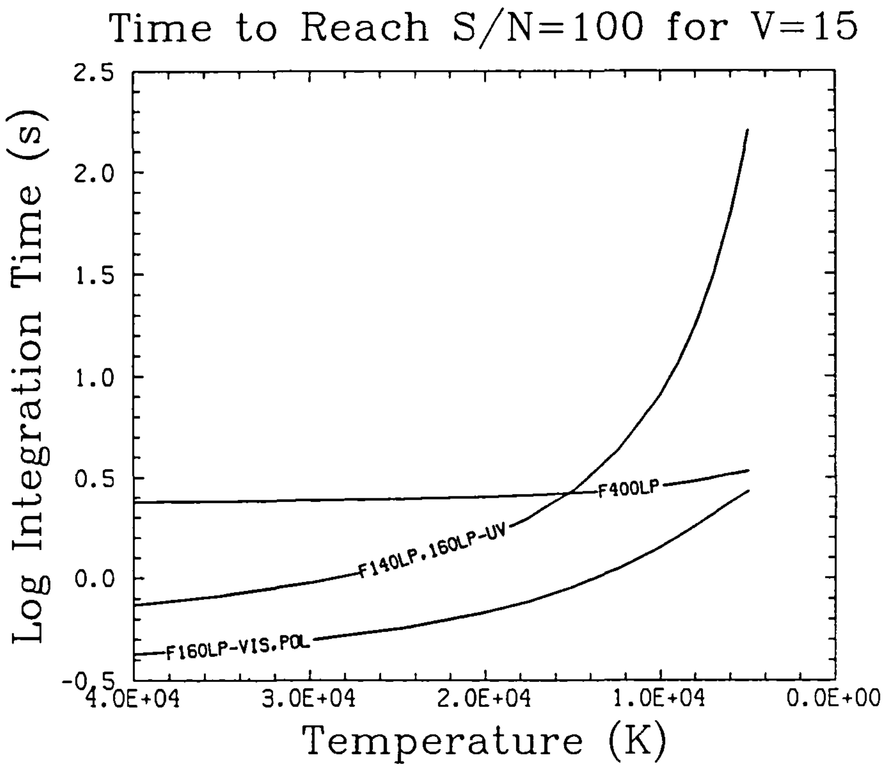

Figure 4–17: *Time to Reach V=15 with S/N=100: Longpass Filters*

4.2 Planning a Typical Observation with the HSP

This section shows how to calculate exposure times, etc., using the information given above and in Chapter 3. The example has a relatively simple goal, but it demonstrates some of the complications that can arise in planning an observation and shows that the considerations discussed in Chapter 3 are often important.

4.2.1 How to Calculate Exposure Times

The exposure time (which must be specified on the exposure logsheet) is the total time ST spends pointing at the target from the beginning to the end of the observation. The exact relation between the exposure time (t_{exp}) and the other times (sample time, delay time, etc.) specified for the observations depends on the mode used:

Configuration	*Mode*	*Exposure Time*
HSP/$\langle D\rangle$	SINGLE	$t_{exp} = N_{samp}(t_{samp} + t_{delay})$, where N_{samp} is the number of samples desired, t_{samp} is the time for each sample, and t_{delay} is the delay time between samples. t_{delay} is usually zero for these modes.
HSP/PMT/VIS	SPLIT	$t_{exp} = N_{samp}(t_{samp} + t_{delay})$
HSP/$\langle D_1\rangle$/$\langle D_2\rangle$	STAR-SKY	$t_{exp} = N_{samp}(t_{samp} + t_{delay})$
HSP/$\langle D\rangle$	PRISM, STAR-SKY	$t_{exp} = N_{samp}(t_{samp,tot} + t_{delay,tot})$, where $t_{samp,tot}$ is the sum of the sample times for the two apertures and $t_{delay,tot}$ is the sum of the delay times for the two apertures. t_{delay} is usually 10 milliseconds *for each aperture* in these modes, so $t_{delay,tot}$ is usually 20 milliseconds.

If a sequence containing a number of exposures is defined, then the total exposure time for the sequence is simply the sum of the individual exposure times.

The sample time and number of samples needed for a particular observation are determined by the scientific objectives of the program: the brightness of the target, the filter used, the time resolution needed, the signal-to-noise required, etc. The next section shows how to calculate the sample time and number of samples for a typical HSP observation.

4.2.2 Polarimetry of the Crab Pulsar

The Crab pulsar is a classic object for high speed photometry. The scientific goal of this sample program is to measure the polarization of the ultraviolet pulse from the Crab pulsar. We want to have about 30 bins across the pulse and to collect about 10^4 photons per bin at the peak of the pulse in order to measure the brightness of the pulse to about 1% and the polarization to ~1.5%.

The (time-averaged) de-reddened spectrum of the Crab pulsar in the UV is approximately

$$F_\nu = 5 \times 10^{-29} \left(\frac{\nu}{10^{15}\,\mathrm{Hz}}\right)^{-0.5} \mathrm{Wm^{-2}Hz^{-1}}$$

or

$$F_\lambda = 1.5 \times 10^{-14} \left(\frac{\lambda}{3000\text{Å}}\right)^{-1.5} \mathrm{erg\ cm^{-2}\ s^{-1}\ Å^{-1}}$$

(*e.g.*, see *Pulsars* by Manchester and Taylor). The extinction to the Crab pulsar is $A_V = 1.6^{\mathrm{m}}$; from the standard interstellar reddening curve (tabulated in the *Faint Object Spectrograph Instrument Handbook*), we can calculate the reddened flux at the wavelengths of the filters we are going to use. Then the counting rate in each filter can be estimated from the data for the polarimetry filters given in Table 4-2:

Filter	λ (*Å*)	A_λ (*mag*)	F_λ (*photons* $cm^{-2}s^{-1}Å^{-1}$)	*FWHM* (*Å*)	*Throughput* (*%*)	*Count Rate* (*cts/s*)
F237M	2370	4.12	6×10^{-5}	280	0.17	1.2
F277M	2770	3.07	1.4×10^{-4}	340	0.39	8
F327M	3270	2.57	2.0×10^{-4}	410	0.29	11

The counting rate is the product of the photon flux density, the collecting area of ST ($\pi[120\,\mathrm{cm}]^2$), the FWHM of the filter, and the throughput of the system.

To calculate the exposure time, several other factors must be taken into account. The amplitude of the pulses is such that the peak brightness of the pulsar is about 10 times the average brightness. Thus, the total exposure time required to get 10^4 counts at the peak brightness ranges from 1.5 minutes to 15 minutes. If the pulse period gets divided into 30 bins (each of about 1 msec duration), then the total observing time must be 30 times that required for the peak bin; it ranges from 45 minutes to 7 hours for the filters listed. Finally, it is necessary to make successive observations through each of the four polaroids associated with each filter, increasing the time required by another factor of 4. Thus we arrive at the following exposure times:

Filter	*Observation Time (hours)*
F237M	28
F277M	4
F327M	3

Apparently the pulsar is too faint (mainly because the interstellar extinction is so large) to allow an accurate measurement of the polarization at 2370 Å in a reasonable length of time. Consequently, the 2770 Å filter is the best choice for the observation.

The sky brightness is relatively small compared to the brightness of the Crab pulsar, so we will not bother to measure or subtract the sky background. This means that we will use SINGLE mode. Only 1 arcsec apertures are available for polarimetry, but they would be preferred for high accuracy even if the 0.4 arcsec apertures were available.

The sample time should be somewhat shorter than a millisecond to make the rebinning of the data into 1 msec bins easier (see §3.2.3); 0.5 msec is a good choice because then the data rate will be about 16 kilobits per sec, which is comfortably under the 32 kbs rate at which the tape recorder stores data (see §3.2.2). (There is no way to get the data rate under 4 kbs.) There will inevitably be gaps in the time coverage due to occultations by the earth (§3.2.2), but the period of the Crab pulsar is so well known that the gaps should not pose any data analysis problems. If there are unexpected problems, the pulsar is bright enough to determine the phase of a short segment of data from the data itself.

To minimize the systematic errors resulting from mis-centering the pulsar within the apertures, we might want to peak up before beginning the observation (see §3.3.3). However, peaking up will probably not be necessary in this case because the polarimetry IDT does not suffer from thermal motion of the aperture images (as do the other IDTs), so its aperture positions will be known very well.

To minimize other systematic errors, the data taken through differently oriented polaroids should be interleaved rather than being taken all at once. Moving from one aperture to the next (by slewing the telescope) requires about 30 sec (§3.2.1); thus, changing polaroids every 10 minutes will increase the total observing time by only about 10 minutes (20 extra slews at 30 seconds per slew).

Finally, it is necessary to specify how the target will be acquired. It should be possible to use the Onboard target acquisition method, in which an HSP image is automatically analyzed to identify and locate the target (§2.5.1). The Crab pulsar is bright enough that it is easily detected in the minimum target acquisition time of 0.2 minute (Table 4-7). However, it is prudent to specify explicitly that the integration time at each point in the image is to be 90 msec; then we can be sure that the rapid pulses will not cause problems. Remember that the points in an HSP image are accumulated one at a time, so a target that varies during the target acquisition data collection may be misidentified or missed entirely. The total target acquisition time for the Crab Pulsar (including the 25 ms per point overhead) is then $400 \times (25 + 90)$ ms $= 46$ s (Table 4-7). Since we are observing with the polarimetry IDT, we will use the target acquisition aperture on the POL IDT.

Chapter 5: Standard Calibrations and Data Products

This chapter describes the way HSP data are usually calibrated and what data products result.

5.1 "Pipeline" Calibrations

The raw data received from the ST pass through an automatic calibration procedure called the "pipeline" before it is received by the observer. For the HSP the pipeline performs 6 steps:

(1) *Reformatting.* The data are put in a standard form which is independent of the particular way it was collected. Interleaved data taken in STAR-SKY mode are divided into two files; data taken with the ALL data format is split into separate digital and analog files. Each data sample (which may be from 8 bits to 24 bits long) is converted to a 32-bit floating point number. The data is written to a FITS-like format called "GEIS" format which can be read directly by the STSDAS analysis routines.

(2) *Convert counts to count rates and apply deadtime correction.* For pulse-counting (digital) data, the raw counts are divided by the sample time to yield count rates, which are then corrected for the non-linearities caused by the deadtime of the counting electronics. This correction is 1% for counting rates of about 2.5×10^5 counts/s. The deadtime is known from laboratory measurements to be a weak function of temperature, so it should be possible to make accurate deadtime corrections for count rates up to at least 10^6 counts/s.

(3) *Subtract dark counts or currents.* The standard dark contribution from the phototube is subtracted. Nominal dark counts and currents are known as a function of both the position on the IDT cathode and the detector temperature. Notice that if a special dark calibration is requested by the observer (via the DARK internal calibration target request described in the *Phase II Proposal Instructions*), it will not be subtracted in the pipeline; instead, it will have to be subtracted using the general purpose data analysis system, STSDAS (see below).

(4) *Convert currents to equivalent count rates.* For current (analog) data, the photocurrents that were measured are converted to the effective count rates that would have been measured by a pulse-counting system with zero deadtime.

(5) *Correct for the instrumental efficiency.* The instrumental efficiency is measured by observing a standard star through the same aperture-filter combination. Comparison of observations of the same standard star taken at different times allows the removal of changes in the HSP sensitivity as a function of time. The pipeline calibration program computes the HSP count rate the target would have had if the HSP sensitivity had not changed.

(6) *Divide observations of extended objects by aperture area.* Note that this applies to sky observations as well as to observations of extended targets.

5.2 Data Products

The results of the pipeline calibration are files containing the HSP count rates as a function of time for the star+sky and (if it was measured) the sky. In addition, the reformatted data (produced by step 1 above) are readily available to the observer. A single observation can generate up to 8 separate data files: a STAR-SKY observation using the ALL data format will generate an uncalibrated data file and a calibrated data file for each of the star/digital, star/analog, sky/digital, and sky/analog data.

Note that the sky background is not subtracted from the star+sky measurement. It was decided that sky subtraction is sufficiently complicated that it is not reasonable to include it in the automated pipeline. Instead, it will be the observer's responsibility to decide how the sky measurements are to be averaged and interpolated before they are subtracted from the star measurements.

Note also that the HSP count rates are not translated either to absolute fluxes or to a standard magnitude system. Both of these conversions depend on knowing the spectral energy distribution of the target star. Keywords in the header of the data will allow conversion to fluxes; the Science Data Analysis System (STSDAS) at STScI will include the tools that are necessary to convert HSP count rates to a standard magnitude system if the target star's color is known or if some shape for the spectrum is assumed. STSDAS will also have access to the calibration data that are required for these translations (*e.g.*, color terms for standard filters and the absolute flux distribution for calibration stars.)

An advantage of supplying the data in the form of HSP count rates rather than absolute fluxes is that the former are independent of the flux distribution assumed for the standard stars. Thus, if the flux scale of the standard spectra is revised, the HSP count rates will not change.

5.3 Special Calibrations

Calibration observations made as a service by the STScI will be sufficient to calibrate most HSP observations. However, there will inevitably be some observations that require special calibrations. For example, a special calibration may be required to measure the strongly varying sky background which is seen during a lunar occultation. As another example, it may be desirable to observe a standard star before and after the target is observed in order to remove small systematic effects (see chapter 3 for more discussion of this).

Any special calibration observations must be requested as part of the observing proposal. The observer is responsible for applying the calibration to the data. It is impossible to say at this time what the accuracy of the standard calibrations will be during the first year after launch, but ultimately the goal will be to remove all systematic effects larger than 0.1% of the signal. Smaller effects will probably always be the responsibility of the observer, and larger effects will almost certainly be present during the year following launch.

Chapter 6: Bibliography

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