Instrument Handbook for the Goddard High Resolution Spectrograph (GHRS)

Version 6.0

For Cycle 6 of the HST science mission

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The STScI GHRS Team

D.R. Soderblom
A. Gonnella
S.J. Hulbert
C. Leitherer
A. Schultz
L.E. Sherbert

This is version 6.0 of the Instrument Handbook for the Goddard High Resolution Spectrograph (GHRS) of the *Hubble Space Telescope.*

Editor and principal author is David R. Soderblom.

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> This GHRS Instrument Handbook supersedes all previous versions. If a conflict exists between this document and another, the document with the latest date of issue should be accepted.

STScI Contacts for Assistance

Function	Contact Name	Title	Phone	e-mail
General instrument questions	David R.Soderblom	GHRS Group Lead	410-338-4543	*soderblom@stsci.edu*
	Stephen J. Hulbert	GHRS Instrument Scientist	410-338-4911	*hulbert@stsci.edu*
	Claus Leitherer	GHRS Instrument Scientist	410-338-4425	*leitherer@stsci.edu*
	Al Schultz	GHRS Instrument Scientist	410-338-5044	*schultz@stsci.edu*
	Lisa E. Sherbert	GHRS Data Analyst	410-338-5036	*lisa@stsci.edu*
	Anne Gonnella	GHRS Data Analyst	410-338-4584	*gonnella@stsci.edu*
Proposal scheduling questions	Presto	Program Coordinators and Liaison Scientists	410-338-5080	*hstquery@stsci.edu*
Any question	SSD "Hotseat"		410-338-1082	*help@stsci.edu*

To get to the GHRS home page on the World Wide Web use this URL:

http://www.stsci.edu/ftp/instrument_news/GHRS/topghrs.html

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Part I: Introduction to the GHRS

Part II: Writing GHRS Proposals

Part III: GHRS Reference Information

Part IV

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Chapter 1   *Introduction*

There are two reasons you may be referring to this *Handbook*. First, you may be considering using the GHRS to observe some celestial object, and you would like to know what the instrument can do and how long it might take. Better yet, your proposal to use the *Hubble Space Telescope* with the GHRS has been approved and you now need to supply all the details of your observations that are needed in Phase II of proposal processing so that you can use the time you have most effectively.

Both tasks may seem daunting at first because any versatile instrument has many options. But for what most people want to do most of the time there are defaults that apply, and the GHRS is, in fact, very easy to use. Once you know that what you want to do falls within the bounds of conventional uses of the spectrograph, you can have some confidence that your observations will be obtained in the form you originally desired. Or you can at least get a sense that what you are proposing is truly unusual and may push the limits of the instrument.

This *Handbook* exists as a basic reference manual for the Goddard High Resolution Spectrograph (GHRS), and describes its properties and operation. This *Handbook* is revised and reissued approximately once each year. This version is written for observers wishing to propose to use the GHRS in *HST*'s Cycle 6, and it supersedes all previous versions. The GHRS is expected to be withdrawn from HST at the end of Cycle 6, so that this is the last opportunity to propose to use the instrument. This is also probably the last version of the *Instrument Handbook* that will be issued.

No *HST* document stands alone in providing complete information because each fills a particular need. The *Call for Proposals*, for example, describes the proposal submission process and provides a summary of the observatory and its instruments. The *Phase II Proposal Instructions* give detailed instructions for providing STScI with the specifications that translate your program into commands that *HST* executes. The instrument handbooks supplement both documents by providing the technical details of instrument performance and operation. The *HST Data Handbook* describes how software takes the raw data from the telescope and transforms it into a reduced and calibrated form for your further analysis and interpretation, and how you can duplicate those steps.

The *GHRS* is now a mature instrument and so we can predict what many observers will need. This *Handbook* is designed around the needs of the majority of users, so that essential information is concentrated in a few sections. Full details must also be given, of course, and they are provided in a reference section. We have also tried to provide the information you need to decide when your observations deviate from the "normal" and involve special aspects.

No handbook of this kind can be complete and error-free until the instrument itself is obsolete. We have, of course, edited it thoroughly, but if significant revisions are called for they will be announced via the GHRS Home Page on the World Wide Web, as with other *HST* news items (the URL is given at the end of this chapter). Please consult with us if you have questions; the means of contact are provided just after the title page.

1.1 This Handbook

This *Handbook* is divided into four parts:

Part I is a summary in which this *Handbook* is described and suggestions are made on how to use this document and how it is related to other *HST*-related documents. Part I also describes how *HST* proposals are processed for review by the Telescope Allocation Committee (TAC) and how successful proposals get turned into commands that the spacecraft can execute.

Part II elaborates on the writing of proposals to use the GHRS, both for Phase I and Phase II. The Phase I proposal is what the TAC sees, and it describes the observations to be made in broad terms. The most important technical decisions to be made regard the target acquisition strategy to adopt and the amount of exposure time to request. The Phase II proposal encompasses all the details that the planning and scheduling systems need to turn your program into commands for the spacecraft.

Part III is a reference section, and it includes the details that a *Handbook* should, without cluttering the introductory explanations.

Part IV is a short glossary of GHRS terms and abbreviations and an index.

Data reduction and analysis are not covered in this *Instrument Handbook* because they are treated in detail in the *HST Data Handbook*. External references have been included where appropriate in order not to duplicate what is available elsewhere, but we have tried to include almost everything you need to know about the GHRS when writing a proposal. If you find that you need information that is not in here, please consult with us.

In some cases we present information here in a redundant way because a discussion of acquisitions, for example, arises in several contexts. We have tried to make each discussion self-contained or at least have cross-references, but you may wish to consult Chapters 2, 3, *and* 4 at times.

1.1.1 Document Conventions

This document follows the usual STScI convention in which terms, words, and phrases which are to be entered by the user in a literal way on a form are shown in a typewriter font (e.g., BRIGHT=RETURN, FP-SPLIT). Names of software packages or commands (e.g., stsdas, synphot) are given in a sans serif font.

Wavelength units in this *Handbook* are in Ångstroms (Å), in keeping with astronomical tradition.

1.2 Changes since the previous version

1.2.1 This Handbook

This version of the *GHRS Instrument Handbook* has had significant rewriting, mostly to incorporate information about the proposal writing software called RPS2. We have also added a chapter on calibrations for the GHRS, as well as a few updates since version 5.0

that were issued electronically. Please bring errors to the attention of a GHRS Instrument Scientist (see back of title page).

1.2.2 Cycle 6 and the End of the GHRS

We anticipate that Cycle 6 will be the last for the GHRS. This has three important implications for proposers:

1.2.2.1 A Short Cycle 6

The second servicing mission for *HST* is scheduled to take place in February, 1997. Since Cycle 6 starts in July, 1996, there is only about half a cycle in which to complete Cycle 6 GHRS observations. Even if time is awarded, GHRS observations that are not completed before the servicing mission will *not* be carried forward into a later cycle. Time-critical observations that must take place after January, 1997, and are intended to be done with the GHRS will be executed only if a launch delay makes that possible. The shortness of Cycle 6 for the GHRS also places other constraints on scheduling and makes use of early acquisitions or complex linkages between observations especially problematic.

Because Cycle 6 is short for both the GHRS and FOS, it is STScI's intention to schedule spectroscopic observations early in Cycle 6 to the greatest extent possible so that as many FOS and GHRS programs may be completed as is possible.

1.2.2.2 Loss of GHRS Unique Capabilities

The Space Telescope Imaging Spectrograph (STIS) will replace most of what the GHRS can do (consult the STIS Mini-Handbook for details). However, the GHRS has a few unique capabilities that STIS will not duplicate. One of those is a demonstrated capability to obtain very high signal-to-noise (1,000 or more) spectra. STIS, by comparison, is expected to be able to provide up to about 100. The GHRS can also count very rapidly: rates of 20,000 counts per second per diode are correctable to a linearity of 1%. STIS, on the other hand, will be limited to a local count rate of ~50 per second per pixel. For most purposes STIS should offer a substantial improvement over the GHRS, but proposers should be aware of these unique qualities of the GHRS in preparing for Cycle 6.

1.2.2.3 Replacing the GHRS

We remind you that the STIS Mini-Handbook is available to outline the capabilities that will be available to you in Cycle 7. You may wish to take STIS into account in making long-term observing plans. In particular, the STIS Mini-Handbook provides a comparison of the sensitivities of STIS and the GHRS for modes providing comparable quality spectra.

1.2.3 Acquiring Faint Objects with the GHRS or FOS

In some cases the G140L grating on Side 1 may provide an efficient means of obtaining a low-resolution spectrum of a source, but acquiring that object can be difficult or impossible with the GHRS' Side 1 because of the limited response of mirror N1 and the maximum permissible STEP-TIME of 12.75 seconds. There are two ways to overcome this problem:

- Acquire the object with Side 2 of the GHRS (mirror N2), then observe with Side 1. Using this technique will add about 40 minutes of overhead time involved in switching Sides, but often that can occur when the spacecraft is in occultation anyway.

- Acquire the object with the Faint Object Spectrograph and then move it to the LSA of the GHRS. The positions of the COSTAR mirrors for the FOS and GHRS are quite close, so that the movement of an object from an FOS blue side aperture to the LSA of the GHRS is only about 1 arcmin, a small enough motion to ensure that the object will fall within the LSA because one set of guide stars will suffice. This method should *not* be used for SSA observations, nor will it usually work for objects acquired with the red side of the FOS.

  This method of cross-spectrograph acquisitions has now been evaluated and tested, and is available for routine use. In some cases, acquiring an object with the FOS is a more efficient of spacecraft time than doing so with the GHRS, even if a GHRS acquisition is possible in principle. Please note that the opposite sense will also work, namely acquiring a "bright" object with the GHRS in order to observe it with the FOS.

1.2.4 Noise Rejection for Very Faint Objects

A special commanding option called FLYLIM can be invoked to reject noise in the GHRS when the object observed is significantly fainter than the level of the background noise. Although only applicable in special situations, it can be very effective. However, using FLYLIM also involves some real risks that can be avoided by other methods. Please see Section 8.5.4 on page 112.

1.2.5 Post-COSTAR Sensitivities

The sensitivity values listed in Chapter 8 are those measured after the installation of the COSTAR mirrors and they are therefore up to date. Version 5 of this Handbook had interim values of the sensitivity.

1.3 Where to find additional information, changes, errata, etc.

As we mentioned, the *Call for Proposals* provides an overview of *HST* capabilities and describes how a Phase I proposal is to be prepared. It goes hand-in-hand with the *Phase I Proposal Instructions*. If your proposal is successful, you will need to submit a Phase II proposal that provides all the specific details we need to ensure that your observations are obtained in the form you intend. This *Handbook* provides much of the information you will need in Phase II, with the proposal procedures themselves in a *Phase II Proposal Instructions* book. There is also a separate document (the *HST Data Handbook*) that describes how to process and reduce GHRS data. We expect that the *Data Handbook* will contain any information in the future that archival researchers may need to know in interpreting GHRS observations.

This *Instrument Handbook* is written to apply to the Goddard High Resolution Spectrograph as it will be configured and will operate in Cycle 6 of the *HST* science program. This *Handbook* supersedes all previous versions, but if another document conflicts with this *Handbook*, you should use the one with the most recent date-of-issue.

You should also be aware of how to get to HST-related information via the World Wide Web. To reach the GHRS Home page, use this URL:

http://www.stsci.edu/ftp/instrument_news/GHRS/topghrs.html

You are always welcome to call us, the STScI GHRS team, to get information when you find yourself confused or at a loss. We prefer e-mail (to the addresses on the back of the title page), but you may contact us by telephone if you wish.

Finally, you will find some additional sources of information in Chapter 9.

1.4 Dedication

As this is being written, STScI is preparing for the Second Servicing Mission, scheduled for April, 1997. At that time we anticipate that the GHRS will be withdrawn from *HST* to leave room for STIS. This is likely to be the last *Instrument Handbook* for the GHRS, and we would like to take this opportunity to thank the GHRS Investigation Definition Team for building and delivering a versatile and robust instrument. The strong demand for GHRS time is ample evidence of the instrument's quality and usefulness. The cooperation of the IDT and its affiliates has been essential, and we are grateful for their help.

**Do not use out-of-date documents as a source of information!
If this *Handbook* does not contain the information you need, please consult us.**

Chapter 2

Instrument Summary —
Why Use the GHRS?

The Goddard High Resolution Spectrograph was built to obtain high-quality spectra of astronomical sources efficiently. The GHRS can also record images of the objects it observes, but that is mostly as an adjunct to its spectroscopic properties to confirm pointing.

2.1 Fundamental properties of the instrument

Here we provide a brief overview of the basic properties of the GHRS. Each of these aspects is described in more detail in the next two chapters. Chapters 6, 7, and 8 provide illustrations of the GHRS and tables of instrument parameters.

2.1.1 Useful Wavelength Range

The GHRS can obtain spectra from about 1150 to 3200 Å. These limits are set by the magnesium fluoride coatings on *HST*'s optics and by the nature of the detectors. The additional two reflections introduced by COSTAR's mirrors significantly reduce throughput at the very shortest wavelengths (i.e., below Lyman-α) so that even very bright stars (e.g., μ Col) have failed to produce detectable flux below 1150 Å. It is possible to observe bright stars out to 3400 Å.

2.1.2 Spectroscopic Resolving Power

With Side 1, observations may be made from 1150 to 1800 Å at $\mathcal{R} \approx$ 2,000, 25,000, and 80,000 (gratings G140L, G140M, and Ech-A, respectively). With Side 2, the options are $\mathcal{R} \approx$ 25,000 from 1150 to 3200 Å (G160M, G200M, and G270M) and $\mathcal{R} \approx$ 80,000 from 1680 to 3400 Å (Ech-B). For certain applications it can be advantageous to use grating G270M to wavelengths as low as 2100 Å because of its higher efficiency.

2.1.3 Photometric Precision and Accuracy

Routine calibrations on standard stars provide flux-calibrated spectra that are accurate to 10%. Relative fluxes obtained at different wavelengths should be good to better than 5%. The repeatability of fluxes is even better, being better than 1%; i.e., it is possible to compare measures of the same wavelength in the same star at different times to within 1% for observations with the LSA.[1]

Within a single bandpass (i.e., one grating setting), relative photometric precision is limited by photon statistics for S/N < 30 and by detector non-uniformities above that, provided that the detectors are being used within the linear portion of their response. With suitable observing strategies, it is possible to achieve relative S/N as high as 900 (Lambert et al. 1994)[2].

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1. Starting in Cycle 4, the routine fluxes delivered by the pipeline data reduction system are no longer on the *IUE* system but instead have been adjusted to conform to models of the white dwarf G191B2B. This can produce systematic differences when comparing observations.

2. References are listed in Chapter 9.

We have found that the photometric sensitivity of the GHRS has not changed with time to within 1% or less. Some preliminary evidence suggests that the sensitivity may be dropping slightly below 1200 Å, but the effect there is no more than about 10%.

See Chapter 5 for a more detailed discussion of GHRS calibrations.

2.1.4 Entrance Apertures

The source to be observed may be placed in a Large Science Aperture (LSA) or a Small Science Aperture (SSA). Because of the installation of COSTAR, the LSA is 1.74 arc-sec square and the SSA is 0.22 arcsec square, although they retain their pre-COSTAR names (2.0 and 0.25, respectively). The LSA allows virtually all the light of a point source to pass (about 95%, depending on wavelength), and that fraction is insensitive to the precise centering of a star. As a result the LSA is the best choice for obtaining reliable fluxes. However, a star can drift some in the LSA, causing some degradation of spectroscopic resolution. This means that the SSA is better for obtaining spectra with the best resolution. The SSA has about 50 to 70% of the throughput of the LSA; using the LSA will degrade resolution by 10 to 20% compared to the SSA because of the wings to the instrumental profile, plus any effects due to smearing.

The LSA has a shutter which automatically closes when an observation with the SSA is being performed, in order to reduce stray light. The LSA is preferred when reliable fluxes must be measured and the SSA is better when a narrow instrumental profile is needed (for line profile work, radial velocities, etc.).

2.1.5 Time Resolution

Most observers use the GHRS to accumulate photons for the time needed to reach the signal-to-noise they desire. In ACCUM mode the exposures may be as short as 0.2 seconds, although use of standard procedures for improving S/N usually limits exposures to no shorter than about 27.2 seconds (see Section 8.3 on page 106). The GHRS has a rapid readout mode (RAPID) that can obtain spectra as often as every 50 milliseconds, but that can only be done by sacrificing many features that are important for producing high-quality spectra. Some details on these observing mode are provided in Chapter 4. Note that *relative* timing of spectra, especially in RAPID mode, can be established quite accurately, but that *absolute* timing is much more difficult to determine because the spacecraft's clock records in units of 1/8 second. If you need very precise times for your observations you should consult STScI.

2.1.6 Operational Complexity

The limited availability of memory on the *HST* spacecraft means that there exists a maximum number of operating commands that can be in place for a single set of observations. That can be a limit for use of the GHRS in certain cases, described later (Section 4.3.2 on page 47).

2.2 A Brief Description of the Instrument and Its Operation

The GHRS has the usual components of an astronomical spectrograph: entrance apertures, a collimator, dispersers, camera mirrors, and detectors. There are also a wavelength calibration lamp, flat field lamps, and mirrors to acquire and center objects in the observing apertures. The apertures were described above in basic terms, and are illustrated in Section 6.1 on page 70. The collimator and camera mirrors are unexceptional and need no further description here (see Section 6.1 on page 70 for details). The important elements are the dispersers and the detectors.

The dispersers are mounted on a rotating carrousel, together with several plane mirrors used for acquisition. The first-order gratings are designated as G140L, G140M, G160M, G200M, and G270M, where "G" indicates a grating, the number indicates the blaze wavelength (in nm), and the "L" or "M" suffix denotes a "low" or "medium" resolution grating, respectively. The GHRS medium resolution first-order gratings are holographic in order to achieve very high efficiency within a limited wavelength region. G140L is a ruled grating. The first two first-order gratings, G140L and G140M, have their spectra imaged by mirror Cam-A onto detector D1, which is optimized for the shortest wavelengths. The other three gratings have their spectra imaged by Cam-B onto detector D2, which works best at wavelengths from about 1700 to 3200 Å, but which is also useful down to 1200 Å.

The carrousel also has an echelle grating. The higher orders are designated as mode Ech-A, and they are imaged onto D1 by the cross-disperser CD1. The lower orders are designated as mode Ech-B, and they are directed to D2 by CD2. Finally, mirrors N1 and A1 image the apertures onto detector D1, and mirrors N2 and A2 image onto D2. The "N" mirrors are "normal," i.e., unattenuated, while the "A" mirrors ("attenuated") reflect a smaller fraction of the light to the detectors, so as to enable the acquisition of bright stars. (The mode designated as N1 actually uses the zero-order image produced by grating G140L.)

Use of the various gratings or mirrors in concert with the camera mirrors produces one of three kinds of image at the camera focus: 1) an image of the entrance aperture, which may be mapped to find and center the object of interest; 2) a single-order spectrum; or 3) a cross-dispersed, two-dimensional echelle spectrum.

The flux in these images is measured by photon-counting Digicon detectors, and the portion of the image plane that is mapped onto the Digicon is determined by magnetic deflection coils. The detectors are the heart of the GHRS and they involve subtleties that must be understood if the instrument is to be used competently.

First, there are two Digicons: D1 and D2. D1 has a cesium iodide photocathode on a lithium fluoride window; that makes D1 effectively "solar-blind," i.e., the enormous flux of visible-light photons that dominate the spectrum of most stars will produce no signal with this detector, and only far-ultraviolet photons (1060 to 1800 Å) produce electrons that are accelerated by the 23 kV field onto the diodes. D2 has a cesium telluride photocathode on a magnesium fluoride window. Each Digicon has 512 diodes that accumulate counts from accelerated electrons. 500 of those are "science diodes," plus there are "corner diodes" and "focus diodes" (see Chapter 6).

Second, both photocathodes have granularity – irregularities in response – of about 0.5% (rms) that can limit the S/N achieved, and there are localized blemishes that produce irregularities of several percent. The Side 1 photocathode also exhibits "sleeking," which is slanted, scratch-like features that have an amplitude of 1 to 2% over regions as large as half the faceplate. The effects of these irregularities could in principle be removed by obtaining a flat field measurement at every position on the photocathode, but that is, in general, impractical. Instead, the observing strategy is to rotate the carrousel slightly between separate exposures and so use different portions of the photocathode. This procedure is called an FP-SPLIT, and with it each exposure is divided into two or four separate-but-equal parts, with the carrousel moving the spectrum about 5.2 diode widths each time in the direction of dispersion. These individual spectra can be combined together during the reduction phase.

Third, the diodes in the Digicons also have response irregularities, but these are very slight. The biggest effect is a systematic offset of about 1% in response of the odd-numbered diodes relative to the even-numbered ones. This effect can be almost entirely defeated by use of the default COMB addition procedure. COMB addition deflects the spectrum by an integral number of diodes between subexposures and has the additional benefit of working around dead diodes in the instrument that would otherwise leave image defects.

Fourth, the Digicons' diodes are about the same width as the FWHM of the point spread function (PSF) for *HST*. Thus the true resolution of the spectrum cannot be realized unless it is adequately sampled. That is done by making the magnetic field move the spectrum by fractions of the width of a diode, by either half- or quarter-diode widths, and then storing those as separate spectra in the onboard memory. These are merged into a single spectrum in the data reduction phase. The manner in which this is done is specified by the STEP-PATT parameter, described in more detail later. The choice of STEP-PATT also determines how the background around the spectrum is measured.

Defaults exist for these parameters and they have been set to yield the best quality of spectrum for the configuration to which they apply (except for FP-SPLIT, which must be invoked explicitly). Details on the defaults are provided later (Section 4.3 on page 46), but we strongly encourage you to use the defaults unless there are compelling reasons not to.

2.3 A Little About How *HST* and GHRS Work

Because of the difficulties of working with and communicating with a satellite in low-earth orbit, and in order to make *HST* more efficient, virtually all actions taken by the spacecraft are planned weeks in advance. Only a small fraction of *HST*'s time can be used for real-time actions that are at the discretion of the observer, and even then the only possible action is deciding which object in the field should be centered in the aperture before a subsequent observation is begun.

This need for detailed planning of *HST* observations lies at the heart of the apparent complexity of the use of the spacecraft and its instruments. At the same time, by carefully laying out every aspect of what you want done you will find yourself with a better understanding of what actually happens and more confidence that the desired results will be achieved.

All *HST* observations begin with an acquisition. An acquisition can be as simple as blindly pointing to particular celestial coordinates, although such a procedure is unlikely to succeed with the GHRS because its entrance apertures are small. For the GHRS, an acquisition usually means a pointing to precisely specified coordinates, then making small motions of the telescope in a spiral pattern to sample the region of sky in the vicinity of the coordinates, and then a peakup motion to center a star in the aperture after on-board software has determined its location. Variations include offsetting from the acquired star to another nearby object or moving the star to the small aperture. In rare cases it may be necessary to perform an interactive acquisition, in which the observer specifies the object in real time. An intermediate possibility is to take an image with one of *HST*'s cameras (or with the GHRS itself) in advance of the spectroscopic observation (by one to two months) and to then derive precise coordinates from that image (an early acquisition). For very faint objects, especially those to be observed with Side 1 of the GHRS, it is possible to acquire the object with the Faint Object Spectrograph before moving it to the LSA.

Once the star has been properly positioned in the appropriate aperture of the GHRS, science observations may begin. In some cases you may wish to use IMAGE mode, which can map the LSA at ultraviolet wavelengths, but in general this part means dispersing the light with one of the gratings and adding up the counts to form a spectrum. A RAPID mode also exists to record spectra that change on very short time scales. The GHRS has no independent microprocessor and so depends on the spacecraft's computer and memory for control of its operations. One implication of that dependence is that there is a maximum number of commands that can be stored at any one time. Since those commands are generally loaded into the spacecraft only a few times per day, that limitation restricts the total number of GHRS exposures that may be made in a 24 hour period (see Section 4.3.2 on page 47). At the same time, image motion within the instrument that is induced by the earth's magnetic field is best dealt with by making individual exposures no longer than about 5 or 10 minutes, thereby increasing the total number of exposures you need to make to get a science observation. In some cases these requirements come into conflict and compromises must be made to accommodate science goals.

Some other relevant aspects of scheduling *HST* observations are:

- Objects in most regions of the sky "rise" and "set" and will be available for science observations for about half of an orbit (about 50 minutes). Longer exposures get spread over several orbits, with a reacquisition of the guide stars at the beginning of each orbit. Some objects sometimes fall within *HST*'s Continuous Viewing Zones (CVZs), which enables them to be observed for long times at high efficiency; see the *Call for Proposals* for details on taking advantage of the CVZs.

- The orbit of *HST* passes through the South Atlantic Anomaly (SAA), which is a region in which the background count rate is very high. The scheduling software simply stops the counting of photons during times when the spacecraft is within the SAA.

- GHRS observations are interrupted if *HST* goes behind the Earth while the observation is in progress. This is called Earth occultation.

2.4 GHRS Modes of Operation

GHRS has several operational modes for target acquisition and obtaining science data. This is meant only as a brief introduction. Section 4.1 on page 38 should be consulted for more details on acquisitions, and other parts of Chapter 4 for ACCUMs, etc.

2.4.1 Target Acquisition Mode

2.4.1.1 Onboard Acquisitions

Most targets observed with the GHRS can be automatically acquired with an onboard acquisition (ONBOARD ACQ). An onboard target acquisition observation consists of distinct phases. Phases 1 and 2 perform initialization and internal calibration functions, and need not concern the observer.

The third phase is called Target Search. A series of small angle maneuvers, called a "spiral search," scans an area of the sky centered on the initial position. The flux coming through the Large Science Aperture (LSA) is measured at each dwell point in the search. If the BRIGHT=RETURN option has been chosen, either explicitly or by default (and it is recommended), the telescope returns to that dwell point which had the greatest number of counts. If BRIGHT and FAINT limits have instead been specified, the flux is compared to these upper and lower limits at each step in the spiral, and if the measured value falls between these limits the target is assumed to be within the aperture and the search immediately stops. You may request that a field map be generated at the final dwell point by means of the MAP optional parameter. You should be aware, though, that approximately two minutes is required for each map, and that many pointings may be made during the search. (If you intend to analyze the maps in real time, the search phase must be done as an interactive acquisition.) If you wish to confirm the spacecraft's pointing, we recommend obtaining an IMAGE *after* the acquisition instead of using the MAP option – see Chapter 4.

The fourth phase is target locate. Although executed as a separate phase of the ONBOARD ACQ, operationally it is identical to an ACQ/PEAKUP executed in the LSA. This process measures the precise location of the target within the aperture, and requests a small angle maneuver to move it to the center. The field map of the LSA may be made *before* the centering maneuver is performed by specifying MAP=END-POINT. If done *after* the centering (in IMAGE mode), the map can be helpful for confirming that the object was placed precisely in the center of the aperture[1]. The final phase of an acquisition is a flux measurement in which the flux entering the GHRS through the final target aperture is measured and inserted into the data. After centering, a second maneuver will automatically translate the object to the SSA if that is the aperture specified for the observation. An ACQ/PEAKUP with "0.25" as the specified aperture is necessary to center the object in the SSA.

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1. Please don't get the wrong impression. Getting an image of the aperture to confirm pointing is rarely necessary or useful and we mention it here mostly for completeness. If you are working in a crowded field, it might help to know exactly what was in the aperture after the fact.

For some kinds of difficult targets an onboard acquisition may not work. Possible causes might be:

- The error in the coordinates is greater than a few arcsec in either declination or right ascension, so that the target lies outside the largest area that the GHRS can search in its onboard procedure.

- The object is a moving target whose coordinates can not be predicted with ±5 arcsec accuracy when the proposal is written. Features in the atmosphere of a planet, and comets are possible examples.

- The object has a poorly known or unpredictably variable ultraviolet flux.

- The target has nearby neighbors of similar brightness – the onboard search process could then center on the wrong object.

- The object has a spatial extent greater than two arcsec. The automatic centering algorithms may not produce acceptable results on objects comparable in size or larger than the Large Science Aperture.

- The object is too faint to get adequate counts with the maximum permissible integration time of 12.75 seconds.

In many cases these problems can be worked around by using an ONBOARD ACQ on a nearby star and then offsetting to the object of interest, or, perhaps, by using the FOS to acquire before slewing the target to the GHRS.

2.4.1.2 Early and Interactive Acquisitions

You may choose to obtain an early acquisition image with WFPC2, FOC, or GHRS itself. In some cases an acquisition image would be helpful, but the field of view of the WFPC2 is not needed. Stationary point sources in crowded but recognizable fields would be examples. In earlier cycles this was done as an EARLY ACQ, but now the initial image is obtained as a first Visit, with a subsequent Visit or Visits with an ON HOLD Special Requirement; see the *Phase II Proposal Instructions*.

The GHRS also has its own "field map" capability which will produce an image of the sky as seen through the LSA. Each map is a square array of 16 × 16 pixels, covering 1.74 × 1.74 arcsec with 0.11 arcsec spatial resolution. A single field map requires a minimum of two minutes to take the data and send it to the ground, and much longer if each point in a spiral search is mapped or if a STEP-TIME longer than the default (0.2 sec) is used. One WFPC2 image requires from three to five minutes, but covers a much larger area of the sky. As a practical matter, if more than one field map would be needed, a WFPC2 image may be a more efficient choice. The FOC could also be an appropriate choice in some situations.

If an interactive acquisition (INT ACQ) is required, the observer must be present at STScI, prepared to inspect the image and identify the target in a timely fashion. Real-time observations are subject to many constraints and are difficult to schedule (they are occasionally impossible). Early acquisition should therefore be chosen in preference to interactive acquisition whenever possible. Your *HST* Phase I proposal should include a justification of your request for real-time observation.

Early and interactive acquisitions are rarely used now. The shortness of Cycle 6 for the GHRS (see Section 1.2.2.1 on page 10) is yet another reason to eschew them.

2.4.2 Science Data Acquisition Modes

There are several modes of science data acquisition, including Accumulation Mode, Rapid Readout Mode, and Image Mode. Each of these modes may be used in conjunction with any of the optical configurations described earlier.

Accumulation Mode

Accumulation Mode (ACCUM) is the normal way of obtaining a spectrum with the GHRS. The name refers to the fact that data can be accumulated in the onboard computer during a long exposure. All of the features of the flight software are available in this mode, making it the most powerful, flexible, and automatic way to use the GHRS. ACCUM mode has two features that make it preferable for most observations.

The first is the ability to make long duration observations with effective and automatic control of the process. The time varying Doppler shift caused by the orbital velocity of the spacecraft is compensated for automatically. The software constantly monitors a set of data quality criteria and can flag, reject, or reobserve individual integrations that fail the tests. Finally, the software can suspend the observation during scheduled or unexpected interruptions, such as occultation of the target by the Earth or passage through the South Atlantic Anomaly, and then resume when the interruption ends. The very low background count rate and absence of readout noise in the Digicons make exposures of hours duration feasible, though it is strongly suggested that these be broken into shorter segments to aid in scheduling and protect against catastrophic data loss in the event of an unexpected problem.

The second category of benefits results from the ability of the software to perform patterns of integrations at closely spaced positions on the photocathode, a process which is referred to as substepping. There are four purposes for this. At the beginning of an observation, the software executes a procedure called Spectrum Y Balance (SPYBAL) to find the optimum centering (up and down, perpendicular to the direction of dispersion) of the image on the diode array. This compensates for minor changes in the image location due to thermal or electrical drifts. The second use is to make multiple (2 or 4) samples per resolution element (1 diode width) to ensure that the digital data satisfy the Nyquist sampling criterion. This is *very* important when the ultimate spectral resolution of narrow features is required. Third, the background adjacent to the spectrum or in the echelle interorder region can be measured. Finally, COMB addition allows the effect of small diode-to-diode sensitivity variations to be minimized and eliminates the holes in the data due to a few inoperative channels. When substepping is used to define the detailed sampling of the spectrum and background, the data obtained at each step are accumulated into one of up to seven distinct "bins" in the memory of the onboard computer.

This overview of the flight software features is not exhaustive, but summarizes those capabilities which are immediately relevant to the acquisition of spectra in ACCUM mode. Several items, namely substepping and exposure control, require the observer to specify certain parameters. These will be described in more detail later in this *Handbook*.

Rapid Readout Mode (sometimes called Direct Downlink)

Rapid Readout Mode (RAPID) is intended to provide excellent time resolution without the overhead times associated with ACCUM mode. The sample time can be between 50 ms and 12.75 seconds, in increments of 50 milliseconds (i.e., 1 to 255 times 50 ms). At the end of each integration the data are read out, either directly through the TDRSS satellite or to the spacecraft science data tape recorder. The flight software cannot execute all of its functions and still allow readouts every 50 ms. When RAPID mode is entered, substepping, data quality checks and exposure control features are deactivated in order to reduce instrument overhead activities to the bare minimum.

The primary factor governing the choice between ACCUM and RAPID is time resolution. In ACCUM mode, the time between exposures can be no shorter than about three seconds for the simplest STEP-PATT (see Section 8.3 on page 106) and is about one minute for more typical cases. If higher time resolution is required, if the source is bright enough to give useful counts in a shorter integration, and if one is willing to sacrifice the flight software control, then RAPID mode is a useful alternative. In RAPID mode, a SAMPLE-TIME of less than 0.33 sec requires the use of the 1 Mb data channel (see Section 4.4 on page 50). Such a high data rate stresses *HST*'s data-handling capabilities and means that only about 20 minutes of observations can be stored. A SAMPLE-TIME of 0.33 sec or more allows for essentially continuous operations.

Image Mode

Images may be obtained in this mode by deflecting the image of the photocathode over the 0.11 × 0.11 arcsec focus diodes. The result is a map similar to that obtained during target acquisition, but without an acquisition being performed. Note that a MAP as part of an acquisition can cover more of the sky than the LSA subtends at one time by small movements of the telescope, whereas an IMAGE is limited to the 1.74 × 1.74 arcsec area of the LSA; see Section 4.2 on page 45 and Section 7.5.3 on page 95.

WSCAN and OSCAN Modes

These are really modifications of ACCUM mode designed for higher efficiency in multiple observations, and they may be requested during Phase II of the proposal process. WSCAN obtains a series of spectra within a given order, incrementing by a specified wavelength increment between each. The result is a spectrum spanning a broader wavelength range than is possible with a single exposure. OSCAN works with the echelle, and uses the magnetic deflection of the Digicon to obtain spectra over a range of echelle orders. The grating carrousel is not rotated, and spectra are obtained at equal values of $m\lambda$, where m is the echelle order. OSCAN is not ordinarily used for science observations. Both WSCAN and OSCAN are just shorthand versions of ACCUM that make it more convenient to write a Phase II proposal but which do not change the way in which the instrument operates.

2.5 Special Considerations for Cycle 6

In preparing a Cycle 6 GHRS proposal, bear in mind that STIS will soon be available. STIS will be able to do most of what the GHRS can do, only more quickly. Thus there are observations which might best be done with STIS. However, the GHRS also has some capabilities that STIS will not provide, namely the means to obtain spectra of very high signal-to-noise and an ability to count photons at very high rates.

2.5.1 Very High Signal-to-Noise Spectroscopy

The best achievable signal-to-noise with STIS is likely to be about 100 because of inherent limitations in the stability of the flat fields of the MAMA detectors. On the other hand, the GHRS has been shown to be able to obtain signal-to-noise ratios in excess of 1,000 when special techniques are employed. We suggest that you consult Gilliland et al. (1992) and Lambert et al. (1994) to see how the GHRS may be used in this way.

2.5.2 Counting Photons at High Rates

For bright objects, STIS will be limited to a maximum local count rate of approximately 50 counts per second per pixel and a global count rate of 300,000 counts per second. However, the GHRS, even at a rate of 20,000 counts per second per diode, can be corrected for paired pulses to an accuracy of about 1%. Thus there are very bright objects for which excellent spectra can be obtained with the GHRS in a short time, whereas STIS may need substantially longer because a neutral density filter would be required. We suggest that you consult the STIS Mini-Handbook to determine how well STIS is likely to perform, and to emphasize the better efficiency of the GHRS in your proposal if there is a substantial difference in exposure time.

Chapter 3

Writing a Phase I Proposal

A proposal for the *Hubble Space Telescope* is written in two phases. In Phase I, you are asked to provide the information needed for the Telescope Allocation Committee and STScI to judge the scientific merit and technical feasibility of what you wish to do. If your proposal is successful, you will be asked in Phase II to provide the specific details and parameters that are needed to turn your proposal into a series of commands that the spacecraft can execute.

These instructions for completing a Phase I proposal are meant to work with the Cycle 6 *Call for Proposals* and *Phase I Proposal Instructions*.

3.1 Planning Your Proposal: Feasibility and Strategy

In Phase I you are trying to determine first of all if your observations are feasible with the GHRS. Feasibility means: Can I acquire the target?; Can I obtain a spectrum or image that will provide the information I need to address my science goals?; and Can that spectrum or image be obtained in a reasonable time?

The next section and Chapter 7 provide the information needed to understand GHRS target acquisitions. The previous chapter and chapter 8 provide information essential for judging whether or not the GHRS can obtain the observations you need. In particular, examine Table 8-1 on page 98, Table 8-3 on page 102, and Table 8-4 on page 103 to lay out your strategy of gratings to be used and central wavelengths, based on your science needs. Chapter 8 also provides the information you need to estimate exposure time.

On the presumption that your observations are feasible, you then want to estimate how much time will be needed. To do so you need to answer some questions:

- Is a standard acquisition adequate for my target, or will I need a real-time or early acquisition?
- Are standard calibrations adequate for my needs or will I need to ask for time for special ones?
- How long will my exposures take?
- How should exposures be divided into visits?
- What is the total time requirement in orbits?

The tools provided here and in the *Phase I Proposal Instructions* should be adequate for estimating the number of orbits a program will require in most cases. However, if you have a very complex program and have access to Phase II documentation for Cycle 5 and the RPS2 software, you may wish to use that software to produce a more detailed estimate of the orbits you may need.

The next chapter will discuss the details needed for your Phase II proposal. However, the distinction between Phase I and Phase II is somewhat arbitrary and we recommend that you read both chapters during both phases of your proposal writing.

Based on the previous chapter, you will have selected one or more modes of operation: IMAGE, ACCUM, or RAPID. In most cases observers want to get a spectrum that takes advantage of the GHRS' features, meaning ACCUM mode.

Further comments on observing strategy are given at the end of this chapter.

3.2 Acquisitions

For most situations, a standard ONBOARD ACQuisition that automatically centers the brightest object in the field into the desired aperture is all that is needed. Such a procedure is especially appropriate for isolated point sources that are beyond our solar system and which have fairly predictable ultraviolet fluxes, i.e., most stars. In other cases, it is possible to use a variation on the automatic procedure to acquire other objects. For example, an extended object or some moving objects may be acquired by first automatically centering on a nearby point-like source and then offsetting to the object of interest. Some potential problem cases are:

- very bright stars, which can saturate the detectors;
- very faint objects for which few counts would be accumulated in the maximum permissible integration time (12.75 sec);
- extended objects that do not have a sharply peaked source to center on;
- objects that are so variable that their brightness relative to nearby objects may be unpredictable;
- moving targets, such as planets and their satellites; and
- crowded fields, in which the automatic centering procedure might get confused.

Even in these cases an ONBOARD ACQuisition will usually work or at least the object can be acquired with the FOS first and then moved to the GHRS' LSA. However, we mention here for completeness interactive (or real-time) acquisition. In an interactive acquisition, the spacecraft obtains a picture of the target's field with one of the cameras (WFPC2 or FOC) or with the field mapping capability of the GHRS itself. This picture is relayed immediately to STScI, where the observer is available to study the image and decide where the telescope should be pointed. Interactive acquisitions are obviously helpful in difficult situations, but the requirement for real-time contact between the ground and *HST*, together with the need to set aside a block of telescope time for the pointing decision to be made, makes interactive acquisitions consume much more spacecraft time than is needed for a standard ONBOARD ACQuisition. Interactive acquisitions require special scheduling and so require greater-than-average work on the part of the planners of *HST*'s time. Real-time contact with *HST* is a limited resource (it cannot exceed 20% of the total time) which must be reserved for genuine need. No GHRS programs in Cycle 4 or 5 have needed interactive acquisitions, and so we anticipate little or no further use of this capability.

A variation on this procedure is to get the field image two months or so in advance of the time the spectrum will be obtained. This used to be called an early acquisition (EARLY ACQ) but is now handled as a separate Visit. An early acquisition takes more time than an on-board acquisition but, unlike an interactive acquisition, it imposes no burden of real-time contact. The observer must be prepared to analyze the early acquisition image quickly (within a week or two) if the positions from it are to be incorporated into the telescope schedule. Again, we have found that early acquisitions have not been needed in practice in Cycles 4 and 5. Moreover, the shortness of Cycle 6 (see Section 1.2.2.1 on page 10) makes early acquisitions especially impractical.

If you wish to use either WFPC2 or FOC for early- or interactive acquisitions you must refer to documents specific to those instruments. Details on the use of the GHRS' imaging capability are provided in the next chapter.

3.2.1 Very Bright Stars

When is a star too bright for an ONBOARD ACQuisition? In practice we are unaware of any real need to use interactive acquisition just because a star is very bright. GHRS acquisitions are done with ultraviolet light, so it is the UV flux of the star that matters. There are no stars too bright to acquire with the attenuated mirror A1, for example. Even with Side 2 it is not necessary to specify an interactive acquisition for a very bright star if the BRIGHT=RETURN option is used. Since the few very bright stars which could cause problems are always the brightest point sources in their immediate area, there is no apparent reason not to use BRIGHT=RETURN with an ONBOARD ACQuisition.

However, in working with bright stars you need to carefully consider the count rate that will occur for two reasons. First, if the count rate is high and the integration time is longer than about 0.6 sec, you can "wrap" the counters. The image of the star is then an annulus and there is no bright core to center on. As long as the STEP-TIME is 0.6 sec or less this should not happen. (The maximum count rate is about 100,000 per second and the counter will hold ~64,000 counts.) Even if "wrapping" does not occur, an acquisition for a very bright star may not work well if the count rate is extremely high. This is because the counters saturate, leading to a Point Spread Function (PSF) with less contrast than for a properly imaged one. In an extreme case the center of the stellar image can be flattened, leading to the wrong "center" being placed into the aperture. Chapter 7 provides the information you need to determine the acquisition count rate.

3.2.2 Faint Objects

You can get a spectrum for as long as you wish with the GHRS, but the maximum permissible integration time per dwell point (STEP-TIME) for a GHRS acquisition is 12.75 seconds. As long as the brightest point in the search area has 1,000 counts or more within the STEP-TIME you choose, your acquisition should work fine, and there is little risk of failure even if you only have ~100 counts in the brightest pixel. If you are using Side 2 of the GHRS (G160M, G200M, G270M, or Echelle-B), there are probably no objects you cannot acquire with a STEP-TIME of 12.75 seconds or less if it is possible to also get a spectrum.

But acquisitions with Side 1 of the GHRS can be problematic. In particular, grating G140L can obtain spectra of objects too faint to be acquired with MIRROR-N1. If you find that you cannot get 100 or more counts in the peak pixel with N1, you have two options. First, you can use MIRROR-N2 on Side 2, which has a much broader response. The penalty for doing this is a delay of about 40 minutes in switching from Side 2 to Side 1. Your other option is to acquire your object with the FOS and then ask for your ACCUM in the LSA. An FOS-assisted acquisition will *not* work for observing in the SSA, but there is no significant time involved in moving the target from the FOS acquisition aperture to the LSA. Note that FOS-assisted acquisitions should be done on the blue side of the FOS because the FOS red side apertures are more distant from the GHRS and it is unlikely to be possible to use the same guide stars throughout. For more information on FOS-assisted acquisitions, see Section 4.1.4.3 on page 41.

3.2.3 Extended Objects

For most extended objects, it may be possible to offset from a nearby point source or at the least the pointing can be specified from an early acquisition image. Interactive acquisitions should be necessary only rarely. Another method is to acquire the object with the FOS and then offset to the GHRS' LSA. You may also use a centering option designed expressly for extended objects, especially uniform ones like the Galilean satellites of Jupiter. Chapter 4 contains more information on this option, known as LOCATE = EXTENDED.

3.2.4 Variable Objects

Objects whose ultraviolet brightness varied often caused acquisitions to fail when it was necessary to specify both BRIGHT and FAINT count limits. The advent of software that automatically finds the brightest object in the field (BRIGHT=RETURN) obviates that problem in most cases. A variable object in a crowded field might benefit from an early acquisition to determine precise coordinates, but an interactive acquisition should generally be unnecessary.

3.2.5 Moving Targets

Sophisticated pointing at moving objects (i.e., objects within the solar system) may require interactive acquisition to be sure the desired portion of the object's surface is centered in the observing aperture. There are cases where an ONBOARD ACQuisition will suffice, especially if the object is small (essentially point-like) and has a well-determined orbit. An ONBOARD ACQuisition can often work well even for a large moving object like Jupiter by first centering on a small object nearby whose relative position is well known (one of Jupiter's moons, for example), and then offsetting to the position of interest on the planetary disk. Solar system astronomers may wish to consult with a moving-target specialist at STScI before specifying the acquisition mode.

3.2.6 Crowded Fields

Work in crowded fields can usually be done by obtaining an early acquisition image, so that you have something to work from to specify the object to be observed, an image that has been obtained with *HST*'s full spatial resolution. The camera observation is usually best done at about the same wavelength that the spectroscopic observations will be made.

The Point Spread Function (PSF) of the GHRS has been restored by the COSTAR mirrors, making it possible to separately observe stars that are very close together. For example, in an Early Release Observation in April, 1994, two stars in R136a separated by only 0.25 arcsec were observed independently. One of these stars was only 0.1 arcsec from a brighter neighbor. This was done by centering on a bright object in the field and then offsetting to the targets of interest. We suggest that you consult with us if you wish to work in crowded fields. Also, see Section 4.1.4.2 on page 40 and Section 4.1.4.5 on page 42.

3.3 Calibrations

A discussion of calibrations and a summary of the GHRS calibration plan for Cycle 5 is presented in Chapter 5. You should not need to measure sensitivity for yourself because the GHRS is highly stable and we believe we have performed sensitivity measures as well as they can be done.

Wavelengths are another matter. The default wavelength scale from routine data processing is good to 1 km s^{-1} rms or better for the medium-resolution and echelle gratings, more than adequate for most needs. However, the wavelength zero point can drift because of temperature changes and the effects of the Earth's magnetic field. Because of these latter effects, we recommend that individual exposures not exceed 5 to 10 minutes in length. That prevents any loss of resolution from smearing.

If the zero point of the wavelength scale of your spectrum is important to your science, you may wish to obtain a wavecal as part of your program. A wavecal is an ACCUM with a TARGET of WAVE specified using aperture SC2. A wavecal should always precede the science observations to which it will apply. Whether or not you ask for a wavecal, you will get an observation called a SPYBAL each time you use a new grating for the first time and about once every other orbit thereafter. A SPYBAL (SPectrum Y BALance) is a wavecal obtained at a fixed wavelength for each grating, and it is used to center the spectrum on the diodes in the direction perpendicular to dispersion. Thus the SPYBAL will not be centered at the same wavelength you are observing, but it is useful for determining a correction to the wavelength zero point, and the accuracy achieved is nearly as good as if a wavecal had been used.

Even if you obtain a wavecal or use a SPYBAL, it will apply only to the ACCUM immediately following it in time. This is because of the drifts mentioned above. For fairly bright objects it is possible to cross-correlate individual spectra to determine offsets and so to create a final spectrum with little or no loss degradation in the wavelength zero point. Such a technique will not work for objects whose radial velocities vary, of course, and so individual wavecals may be necessary. They may be needed for faint objects too.

You may wish other calibrations that are not described here. If they are not part of our calibration program (see Chapter 5) then you will probably need to obtain them yourself and will need to request the time to do so. Please consult us if you have questions.

3.4 Exposure Estimation

3.4.1 Sensitivity

The sensitivity of the GHRS and *HST*'s Optical Telescope Assembly (OTA), using the LSA, has been determined from observations of stars with known ultraviolet fluxes. The sensitivity is designated as S_λ, and has units of (counts diode^{-1} sec^{-1}) for each incident (erg cm^{-2} sec^{-1} Å). It varies as a function of wavelength for each grating. You must first estimate the intrinsic flux of your target and then multiply that by the appropriate value of S_λ to yield an estimate of the count rate to be expected for a particular grating configuration at the chosen wavelength. Sensitivity curves for the first-order gratings are provided in Table 8-2 on page 100 and for the echelles in Table 8-3 on page 102 and

Table 8-4 on page 103. The synphot tool in stsdas can be useful for exposure estimation.

In the echelle configurations, the sensitivity varies with wavelength across each order. This behavior is characteristic of all echelle spectrographs, and is called the Blaze Function. The basic nature of the variation with wavelength is similar for all orders, and can be parameterized in terms of the product $m\lambda$, where m is the order number and λ is the wavelength (Å). The shape of the blaze function, normalized to a peak value of unity, and plotted as a function of $m\lambda$ is shown in Section 8.2.3 on page 106. The sensitivity at any wavelength in any order can be estimated by multiplying the peak response of that order by the relative response shown. The blaze function, relative to the center of an order, falls as low as 0.25 at the end of the free spectral range and its effect should not be omitted in exposure calculations.

3.4.2 Reddening

Corrections for ultraviolet extinction in the interstellar medium are included in Section 8.4 on page 108. These are standard values, and their applicability in specific situations is left to the judgment of the observer.

3.4.3 Background

There are several potential sources of background counts, including detector dark count, electrical interference or cross talk with devices either within the GHRS or the spacecraft, and effects caused by the charged particle radiation environment of the *HST* orbit.

The GHRS detectors themselves contribute little to the dark count. During "thermal vacuum" testing prior to launch, the detector dark count rates were observed to be approximately 0.0004 counts $diode^{-1}$ sec^{-1}. On-orbit, the background is caused primarily by Cerenkov radiation bursts induced in the faceplate of the Digicon by cosmic rays. This causes the actual background to range from 0.004 to about four times that, depending on the orbital position of *HST*. For planning purposes these mean values suffice: 0.011 counts s^{-1} $diode^{-1}$ for D2 (Side 2) and 0.008 counts s^{-1} $diode^{-1}$ for D1 (Side 1). The counts appear to be randomly distributed in time, so that the "noise" in the dark count is the square root of the total counts accumulated during the observation. If one is observing very faint objects with low count rates the background can influence the signal-to-noise ratio of the data. Formulae for making quantitative estimates of S/N are given in Section 3.4.5 on page 33. At the present time there are no known sources of interference or cross talk which affect the detector count rates.

The GHRS is equipped with both hardware (automatic) and software capabilities to recognize and respond to cosmic ray and trapped particle events. You may invoke the software capability by specifying CENSOR = YES on an exposure line in Phase II. This causes rejection of individual segments of data if they included a specified number of photons arriving within a short (8 μs) interval, as happens with cosmic rays. Any rejected integration is repeated, so there is no loss of total exposure time. You should only use this anticoincidence rejection on faint targets, since on bright targets the interval between actual photon events will be small and real counts would be rejected. We recommend using CENSOR = YES only for count rates less than about 0.1 counts s^{-1}

diode^{-1}. The expected dark count reduction is ~10% (for more details on CENSOR, see Section 8.5.3 on page 110).

For extremely faint sources for which the expected count rate is well below the expected dark level, it is possible to use a special commanding option called FLYLIM. This option, if pertinent to your needs, should be explored with a GHRS Instrument Scientist. See also Section 8.5.4 on page 112. FLYLIM relies on the fact that much of the noise comes in bursts so that those spectra with overall counts above some threshold can be rejected. This then involves the risk of rejecting source counts as well if the source count rate has not been accurately predicted. An alternative to FLYLIM is to use RAPID mode. That results in some loss of data quality, but it is then possible to go back into the observations after the fact and to design algorithms optimized to extracting the best signal.

An external source of background which can potentially be a problem during the acquisition (and sometimes the observation) of faint targets is geocoronal Lyman-α. This problem and what to do about it are discussed in Section 7.4.2 on page 94.

The final cause of background counts is passage through the dip in the Earth's Van Allen radiation belt called the South Atlantic Anomaly (SAA). SAA passage occurs on 7 of 15 daily orbits of *HST*. During the most central of these passages, dark count rates increase about two orders of magnitude, to about 1 count diode^{-1} sec^{-1}. A contour around the SSA which corresponds to 0.02 cts/s/diode is known and no GHRS observations are scheduled when the *HST* is within this zone. We have now made it possible for the observer to specify a different SAA contour if they wish to do so. For example, observations of a very bright star may be less sensitive to background and so may tolerate an SAA contour that allows observations to be scheduled more flexibly.

3.4.4 Scattered light

The presence of stray and scattered light in a spectrograph is an effect which can influence the planning and execution of an observation, as well as the reduction and interpretation of the data. None of the optical configurations which include first order gratings has any serious problem with scattered light. The high quality of the imaging optics and holographic diffraction gratings and the effectiveness of the baffles have successfully minimized the stray light. On-orbit measurements indicate that it amounts to less than 10^{-3} when using the SSA, and at most a few times 10^{-3} when using the LSA (these are in units of the peak intensity).

In the echelle configuration, both the echelle and the cross-dispersers are ruled gratings. This fact, plus the presence of light from sixteen orders simultaneously on the photocathode, results in a detectable level of background radiation. The irradiance on the photocathode due to scattered light (measured as count rate per unit area) amounts to a few percent of the signal in the order. Two factors complicate this effect. The first is a geometrical effect caused by the fact that the science diodes are 400 μm tall, while the image of the spectrum is only about 55 μm high. Thus about 1/8 of the diode is illuminated by the spectrum+background, while the rest is measuring background, meaning that a weak background irradiance is multiplied to the point that a significant fraction (anywhere from 2 to 50%) of the gross count rate on a diode may be due to background. The measured scattered light background can be calculated from information in Table 8-3 on page 102 and Table 8-4 on page 103. It varies significantly with order number.

The second complication arises at the short wavelength ends of the echelle format. Below a wavelength of about 1800 Å with Echelle B (or 1250 Å with Echelle A), the spacing between orders is comparable to the length of the diodes, and it is difficult to make a clean measurement of a single order. The diode array has four large "corner diodes" which are long (1 mm) in the direction of the echelle's dispersion, but narrow (100 μm) in the cross-dispersion direction. These diodes may be used to sample the interorder background without the problem of contamination by in order light, but they do not provide any spatial resolution. The system will default to use of the corner diodes when that is appropriate. At a minimum, the time spent measuring the background should be about 10% of the time spent on the spectrum. If the goal is to achieve a very high signal-to-noise ratio in the net spectrum, it may be necessary to devote a greater fraction of time to the background measurement. Suggestions for estimating signal-to-noise ratios are made in the next section.

In order to reduce stray light, there is a shutter over the LSA which automatically closes whenever the SSA is being used for an observation. There is no shutter on the SSA. Thus a wavelength calibration exposure obtained with a bright star in the SSA will result in a combined spectrum of the two because the aperture for the wavelength calibration lamp (SC2) is displaced from the SSA in the same sense as the direction of dispersion. Usually you can subtract the stellar spectrum to recover the wavelength calibration. This contaminated calibration spectrum should be adequate for calibrating the wavelength zero point of your spectrum even with bright stars.

More detailed quantitative information on background and scattered light in the GHRS is provided in Section 8.2 on page 102 and Section 8.5.1 on page 109.

3.4.5   Signal-to-noise

There are several factors which influence the signal-to-noise ratio achieved, including statistical (Poisson) noise in the detected spectrum, dark count noise in the detector, scattered light in the spectrograph, diode to diode gain variations, and granularity in the photocathode sensitivity. For signal-to-noise ratios up to approximately 30, statistical fluctuations in the signal and background will dominate. Diode to diode variations are extremely small, and are accounted for in the routine calibration procedures. Cathode granularity will become important if a signal-to-noise ratio greater than 30 is to be achieved, and must be treated separately. There are also some photocathode blemishes with amplitudes greater than ~3%. For sources observed through the small aperture the sky background should not contribute significantly to the noise, except, perhaps, when observing at Lyman-α.

3.4.5.1   Photon Noise

The following equations may be used to estimate signal-to-noise ratio, depending on the relative importance of scattered light and dark count.

Case 1. Neither scattered light nor dark count are important.

Let:

s = signal strength (counts diode^{-1} sec^{-1}) estimated by multiplying the stellar flux by the sensitivity at the desired wavelength.

t = duration of the observation in seconds. This total time will be divided among the separate substep bins.

n_s = the number of adjacent diodes that will be binned together to produce an effective resolution element. Usually n_s = 1. This is not the merging of substep bins, but the deliberate averaging to increase signal-to-noise at the expense of resolution.

Then

$$(S/N)^2 = sn_s t$$

This formula would be appropriate for relatively bright objects observed with any first order grating.

Case 2. Dark count is important, scattered light is not.

Let:

d = dark count rate in counts diode^{-1} sec^{-1}.

Then

$$(S/N)^2 = \left(\frac{s/d}{1 + s/d} \right) sn_s t$$

If the signal is less than about ten times the dark count rate, the factor in parentheses should be included in the estimate. This formula would be useful if STEP-PATT=5, for example, were used with a first order grating to measure a faint source (see Section 8.3 on page 106).

Case 3. Scattered light is important, dark count is not.

Let:

f = fraction of time spent measuring the spectrum. (See Table 8-5 on page 107)

b = scattered light as a fraction of the signal in the adjacent orders.

Then

$$(S/N)^2 \approx \frac{f}{1 + b} sn_s t$$

This formula gives a good estimate of the performance for observations with the echelle gratings. This formula assumes that the background bins are heavily smoothed. Most of the high frequency statistical noise in the background bins is thus suppressed.

Case 4. Both scattered light and dark count are important.

Let:

n_b = number of adjacent diodes to smooth the background bins over before subtracting. Experiments with ground-based data indicate that $n_b \approx 10$ gives the best results.

Then

$$(S/N)^2 = \frac{s^2 t}{s\left[\frac{1+b}{n_s f} + \frac{b}{n_b(1-f)}\right] + d\left[\frac{1}{n_s f} + \frac{1}{n_b(1-f)}\right]}$$

There are two ways to use these formulae. If you need a certain S/N to do the scientific analysis, use the appropriate equation to solve for the required exposure time t. Alternately, you can decide to devote a fixed length of time to the observation, and use the equations to estimate what S/N will be achieved.

3.4.5.2 Fixed Pattern Noise

The formulae just presented suggest that the signal-to-noise ratio increases in proportion to the square root of the exposure time. These relations only hold true until S/N $\approx$ 50 or so is reached. At higher signal levels the photocathode granularity described in Section 4.3 on page 46 will become the limiting factor. For better S/N you need to use the FP-SPLIT option (see Section 4.3 on page 46). Rather than merely averaging the four FP-SPLIT sub-exposures, the data analysis procedure solves for the two vectors representing photocathode granularity and the spectrum. S/N well in excess of 100 has been obtained this way on bright targets.

Achieving extremely high signal-to-noise (200 or more) is possible by obtaining a number of spectra, each with FP-SPLIT but at slightly different grating positions. See Lambert et al. (1994) for a discussion.

3.4.6 Example of Exposure Time Estimation

Here is a very simple example to illustrate how an integration time may be computed. Suppose that the goal is to obtain a spectrum of a 13th magnitude B0 star at 1900 Å, with the G160M grating and with a signal-to-noise of 25 per diode in the continuum. In this case we will assume that this star has not been previously observed in the ultraviolet so that there is no *a priori* knowledge of the UV flux.

To be specific, take the star to have a spectral type of B0I, $V=12.89$, and $(B-V)=0.63$. The calculation requires:

- The dereddened flux at 5550 Å.

    The unreddened color for this spectral type is $(B-V)_0 = -0.24$, so that $E(B-V) = 0.27$. The total visual extinction is then $R \times E(B-V) = 3.1 \times 0.27 = 0.84$, leading to a dereddened magnitude of $V_0 = 12.05$. The interstellar extinction law is from Code et al. (1976). The dereddened flux at 5500 Å is then
    $F_{5550} = 5.4 \times 10^{-14}$ erg s^{-1} cm^{-2} Å^{-1}.

- The expected flux at 1900 Å.

    The model atmospheres of Kurucz (1979, ApJS, 40, 1) predict $F_{1900}/F_{5550} = 23$ for a star with $T_{eff} = 25\,000$ K. This leads to a flux of $F_{1900} = 1.2 \times 10^{-12}$ erg s^{-1} cm^{-2} Å^{-1} at 1900 Å for the unreddened star. Reddening will diminish this by a factor of $10^{-0.4 \times A(1900)}$, where the absorption at 1900 Å can be determined from the data in Section 8.4 on page 108; the result in this case is $A_{1900} = 2.26$. We therefore predict this star to have a flux at 1900 Å of 1.5×10^{-13} erg s^{-1} cm^{-2} Å^{-1}.

- The detected count rate.

For G160M at 1900 Å, the sensitivity is $S_\lambda = 5.2 \times 10^{11}$, in units of counts diode^{-1} sec^{-1} per incident erg s^{-1} cm^{-2} Å^{-1}. This leads to a count rate of 7.8×10^{-2} counts sec^{-1} diode^{-1}. An integration time of about 2.25 hours would lead to approximately 625 detected counts per diode, or the required signal-to-noise of 25. This neglects the effects of dark, which should be an order-of-magnitude below this count rate.

3.5 Constructing Visits

In putting together your Phase I proposal here are some things to remember.

3.5.1 Acquisitions

You will need to allow time for an acquisition in virtually all cases. An ONBOARD ACQ with the GHRS should be used unless it will clearly not work. An FOS-assisted acquisition is a satisfactory alternative, but early- and interactive acquisitions are to be avoided.

If the STEP-TIME you need to get 100 or more counts in the peak pixel exceeds about 2 seconds then you have a faint-target acquisition, and you should use the longer time on the Phase I work sheets. This is because for faint targets the LOCATE phase of the acquisition takes a lot longer, just as the spiral search part at the beginning does. The LOCATE phase accurately centers your target in the LSA.

For very bright stars you may have to acquire with MIRROR-A2 or MIRROR-A1. In either case you must allow for more time for the acquisition because internal calibrations of the mirror locations take longer (because they reflect less light).

3.5.2 Calibrations

Ask for a wavecal if you believe the default wavelengths are not adequate for your needs and allow time accordingly. A typical wavecal requires about one minute of exposure time, or about 5 minutes of spacecraft time.

3.5.3 Side Switching

When you use G140L, G140M, Echelle-A, MIRROR-A1 or MIRROR-N1, you are using Side 1 of the GHRS. When you use G160M, G200M, G270M, Echelle-B, MIRROR-A2 or MIRROR-N2, you are using Side 2. You may switch back and forth between these two detectors, but doing so requires a wait of about 40 minutes each time to allow for the detector to reach stability. Thus it is generally to your advantage to construct visits so that they only use one Side or the other, or at least so switching is minimized. It may often be possible to have the side switch occur during target occultation if the switch coincides with the boundary between whole orbits of observation.

3.5.4 Memory Usage

A long series of observations with the GHRS on a single target with many different grating settings can result in a command load for the telescope that exceeds its memory. This is most frequently encountered with echelle observations at many wavelengths. See Section 4.3.2 on page 47.

Calibration of the GHRS

5.1 Calibration Philosophy

Calibration means determining the detailed properties of an instrument, so that the quantities actually measured and recorded (counts per pixel for the GHRS) can be translated into astrophysically useful numbers (flux versus wavelength), as well as the uncertainties in those numbers. The calibration program for the GHRS has changed significantly over the years as we have come to understand the instrument more fully. After the 1993 Servicing Mission, for example, the GHRS was characterized in nearly every mode and entirely from scratch. This was done because the COSTAR mirrors fundamentally affected throughput and because Side 1 of the GHRS was being restored to service after a prolonged outage.

Calibration is of three types: characterization, monitoring, and special tests. **Characterization** is the detailed determination of instrument properties, either initially, or at a later time if thought necessary. **Monitoring** consists of an ongoing series of short tests to check that the instrument continues to operate normally. **Special tests** are one-time programs to check a new operating feature or the like.

Aside from the one-time changes imposed by COSTAR and the reactivation of Side 1, the GHRS has been a very stable and reliable instrument. Therefore the calibration programs for Cycles 5 and 6 consist mostly of monitoring programs, with a few special tests and one characterization. What we measure is our ability to establish the wavelength and flux scales of spectra. We also check basic properties of the detectors on a regular basis and examine other aspects of the instrument.

5.2 Sensitivity

"Sensitivity" as a number is the conversion factor between measured counts per second per diode at some wavelength to ergs per square centimeter per second per Ångstrom. Those conversion factors have now been measured for all the gratings of the GHRS except G140M as part of instrument characterization (the measures for G140M were deferred to Cycle 5 because that grating was almost unused in Cycle 4). We have also confirmed that none of the measured sensitivities appear to change with time with one possible exception: There is preliminary evidence that the sensitivity of the GHRS is declining slightly for wavelengths below 1200 Å. This decline is no more than about 10% and there are possible systematic effects that have not been ruled out completely.

The Cycle 5 sensitivity monitoring program observes a standard star four times per year at a series of wavelengths for all of the first-order gratings of the GHRS and once per year for the echelle gratings. We are, of course, paying particular attention to the wavelengths below 1200 Å. Our experience with these observations allows us to note the following:

* Repeated observations of the same star at the same wavelength (but at different times) should be repeatable to about 1%. This is the **precision** of sensitivity.

* Observations of the same star at different wavelengths are comparable to about 2 to 5%, depending on how close together the two wavelengths are. This value depends on our knowledge of the intrinsic fluxes of the calibration stars as well as knowledge of the GHRS and depends on such matters as continuum placement, for example.

- Fluxes on an absolute scale are good to within about 10%; this is the **accuracy**. This value of 10% is limited by systematic effects that are impossible for an observer to remove.

The stable performance of the GHRS means that it is impossible to improve substantially on the flux calibration by obtaining your own calibrations.

5.3 Wavelengths

The GHRS has a spectrum calibration lamp which is used by specifying SC2 as the aperture with WAVE as the target. It is a platinum-neon hollow cathode lamp manufactured by Westinghouse, providing a rich array of emission lines throughout the ultraviolet region that the GHRS observes. The lines are bright enough so that a 30 to 60 second exposure will yield a good comparison spectrum at almost any wavelength, although longer times are needed at some echelle settings. The lamp has its own aperture, offset from the two science apertures of the GHRS. SC2 forms its spectrum at the same y deflection as the SSA, but displaced in x (the direction of dispersion). The lamp aperture is 67 microns square and it forms Gaussian-shaped images with FWHM = 1.1 diode widths.

A wavelength calibration exposure made with the star in the SSA may be contaminated by the stellar spectrum. This is because the SSA has no shutter and the fact that the SC2 aperture is in line with the SSA. This contamination is rarely a serious problem, however, because it is possible to subtract the stellar component. Also, wavelength calibration exposures are generally used to just confirm the zero-point of the spectrum and not to obtain a full wavelength solution.

For a comprehensive listing of the platinum lines, see Reader et al. (1990).

5.3.1 Aperture Offsets

The light from the spectrum calibration lamps does not enter the spectrograph along the same path that starlight takes. This introduces a wavelength shift that must be compensated for in determining the wavelength solution. The data reduction software incorporates corrections that were determined during pre-flight ground testing (new values are being measured in Cycle 5).

5.3.2 Thermal Effects

The image formed by the Digicons is affected by the thermal environment within the GHRS, which in turn is influenced by whatever electronics happen to be on or off in the GHRS and the other instruments. The temperature inside the GHRS can be monitored and the image motion calibrated. This correction is also provided for in the data reduction software. However, this correction is applied only once to a given exposure line. We recommend that the exposure times for individual exposure lines be kept shorter than about one hour as long as you do not encounter problems with using too much on-board memory (see Section 4.3.2 on page 47).

5.3.3 Geomagnetic Effects

As for overall image stability, geomagnetic effects influence wavelength stability. Long exposures should be divided into units of about 5 minutes each, the time over which the wavelength scale does not change measurably.

5.3.4 Calibrating the Wavelength

The precision and accuracy of the wavelength scale of a GHRS spectrum depend on:

- The carrousel position (geometric factors) and the repeatability of that position.

- Motions of the spectrum on various time scales due to thermal effects and the earth's magnetic field, among other things.

The quality of the wavelength scale is primarily an issue with ACCUM mode observations; RAPID mode observations cannot be interrupted and are usually made to look for short-time-scale variability, not wavelength shifts. Our requirement for routine wavelength calibrations is to have them good to about one diode rms. We achieve much better than this in practice. In particular, the default wavelength scale (i.e., the dispersion) is reliable to about 2%, and the zero-point can be established to within about 0.2 diode by obtaining a wavelength calibration exposure just before your ACCUM.

The GHRS wavelength monitoring program runs four times per year for both the echelles and first-order gratings to confirm that anomalies are not occurring and also to build up the database used to establish how motions depend on temperature, time, and magnetic field.

5.4 Detector Properties

Some basic properties of the GHRS Digicon detectors are measured four times per year and checked for consistency with previous measurements. These measurements include background and some properties of the electronics.

5.5 Other Properties

In Cycle 5 we expect to obtain observations to determine more precisely the Point Spread Function (PSF) at the GHRS apertures and the degree of image motion in the apertures over the course of an HST orbit. For Cycle 6 we anticipate doing no more than a minimal monitoring program, which should be adequate to ensure the quality of the archival data for the GHRS.

5.6 Cycle 5 Calibration Summary and Description

The table on the next page and the sheets that follow provide a summary of our Cycle 5 calibration plan.

Table 5-1   Proposed GHRS Cycle 5 Calibration Plan

ID	Proposal Title	Number of executions in Cycle 5	Accuracy Requirement	Estimated Time (orbits) External	Internal
Routine Monitoring Programs					
6168	GHRS Pulse Height Analysis/Ion/ Threshold Test	1	N/A		6
6169	Echelle Wavelength Monitor	4	1 diode		12
6170	GHRS Long-term Sensitivity Monitor for G140M and Echelles	1	2% relative	6	
6171	CRIMP1: Side 1 Integrated Monitoring Program	4	See summary sheet	4	28
6172	CRIMP2: Side 2 Integrated Monitoring Program	4	See summary sheet	12	32
Special Calibration Programs					
6209	G140L Granularity Test	1	2% relative	4	
6210	GHRS Scattered Light Test	1		4	
6212	G140M Sensitivity and Vignetting	1	10% absolute, 2% relative	3	
6213	GHRS Aperture Offsets	1	1 diode	16	
	TOTAL TIME (for all executions)			49	78

5.6.1 Program 6168: GHRS PHA/Ion/Threshold Adjustment Tests—Cycle 5

Purpose: The purpose of this test is to determine the optimal threshold settings for the GHRS detector diodes.

Description: This internal test performs a pulse height analysis to determine individual diode response as a function of threshold for GHRS detectors 1 and 2. Based on this evaluation new thresholds may be determined for optimal GHRS operation. Also included is one ion test which is a PHA of twice normal threshold to look for ion events (which accelerate back up the 22 kV potential of the tube, liberate electrons from the photocathode, and produce events of twice normal energy (this should be a very low, stable rate)).The final test will determine the optimal, non-standard discriminator thresholds for the few anomalous channels on both detectors. A 15 second flat field observation followed by a 210 second dark count is performed at each of 10 discriminator threshold values for each detector. Cross-talk tables are disabled at the start of this test and re-enabled at the end.

This test will execute once during Cycle 5.

Fraction of GO Programs Supported: This test supports 100% of GHRS observations.

Time needed: Internal–6 orbits (3 for each detector).

5.6.2 Program 6169: GHRS Cycle 5 Echelle Wavelength Monitor

Purpose: The purpose of this test is to determine the dispersion solution for the GHRS echelle gratings over the full range of wavelengths covered by the echelles.

Description: This test is an internal test which makes measurements of the Pt-Ne spectral calibration lamp SC2. The spectra obtained are used to calibrate the carrousel function, Y-deflection function, resolving power sensitivity, and scattered light. This proposal defines the spectral lamp test for both Ech-A and Ech-B.

This test will executed every 4 months during Cycle 5 for a total of 3 times.

Fraction of GO Programs Supported: This test supports all echelle observations (37% of all GHRS observations).

Time needed: External–12 orbits (3 orbits for both echelles, 4 times in the cycle).

Special Requirements: Some wavelengths are out of the nominally useful range but are used in determining the calibration.

Accuracy Requirement: 1 diode RMS for pipeline calibrated wavelengths.

5.6.3 Program 6170: GHRS Echelle and G140M Long-term Monitor—Cycle 5

Purpose: The program contains a series of observations to monitor the long-term (timescale: 1 year) sensitivity of Ech-A, Ech-B, and G140M.

Description: This proposal defines a series of observations that will continue the long-term monitor of Ech-A, G140M, and Ech-B. Ech-A and G140M observations will be made both through the LSA and the SSA. Ech-B observations are through the LSA only. μ Col is used for all observations. For the echelles, OSCAN observations will measure the sensitivity near the blaze peak. The setups for Ech-B are chosen to be the same as those used in the Science Verification period, to be able to compare directly to the original calibrations. WSCAN observations will scan across $m=20$ in Ech-B. Ech-A is used with an OSCAN at the blaze peak ($m_\lambda =56100$), plus one WSCAN. G140M is used at 1100, 1200, 1300, 1400, 1500, and 1600 Å.

Instrument Configurations:

    Ech-A: OSCAN;

    Ech-B: OSCAN, WSCAN;

    G140M: ACCUM.

GO Programs Supported: GHRS programs using Ech-A (19%), Ech-B (18%), and G140M (17%).

Time needed: Total of 6 orbits, 3 orbits for Ech-A + G140M, and 3 orbits for Ech-B.

Special Requirements: There are no stringent special requirements. We only request that the observations be executed in the middle of Cycle 5 (to within about 2 months).

Accuracy: The goal of this program is to monitor and document the long-term behavior of the echelle and G140M sensitivities. The sensitivities found in this program will be compared to previous measurement obtained for the same star and with the same instrument configuration The relative accuracy should be at least 2%.

Products: The results of the test will be documented in an *Instrument Science Report.* The ISR will be published within two months of completion of the program. Database updates will only be performed if anomalies are detected.

5.6.4 Program 6171: CRIMP1—Cycle 5 Condensed-Regimen Integrated Monitoring Program for Side 1 of the GHRS

Purpose: The program monitors the sensitivity, wavelength and detector calibrations of Side 1 at a rate of 4 times per year.

Description: 4 times per year, the following observations will be done:

- Detector calibrations:

    1) dark count measurement.

    2) focus check at nominal high voltage and tweak current.

    3) flat field exposure at center of photocathode.

    4) coarse sample mapping function at central y deflection.

    5) coarse line mapping function at central x deflection.

- Sensitivity monitoring:

    The sensitivity calibration of the GHRS Side 1 grating G140L will be monitored with the UV spectrophotometric standard star BD +28°4211.

- Wavelength monitoring:

    The spectral cal lamp mini-functional test for the first order gratings will be done. It is an internal test which makes measurements of the lamp (SC2). It is used to monitor the carrousel function, Y deflections, resolving power, and sensitivity.

Instrument Configuration:

    SAFE1: RAPID,PHOTOSCAN;

    G140L: ACCUM;

    G140M: ACCUM.

    All observations are with the LSA or the SC2 aperture.

GO Programs Supported: GHRS programs using gratings G140M (17%) and G140L (44%) for wavelengths and sensitivities. The detector calibration part supports Ech-A (19%) in addition to G140L and G140M.

Time needed: Total of 24 orbits (6 orbits per execution).

Special Requirements: One complete set of observations (detector, sensitivity, and wavelength) should be on one SMS. The detector calibrations themselves should be executed within 24 hours. The 3 repeats should occur should occur every 90 ± 10 days.

Accuracy: The primary goal of this program is to check for anomalies in basic GHRS properties and calibrations. Sensitivities are regarded as anomalous if they differ from past measures by more than 2%. Dark measures should fall within the bounds of previous observations. Wavelength monitoring is done to build the database upon which the wavelength calibration program is based.

Products: The results of the test will be documented in an *Instrument Science Report*. The ISR will be published 2 months after completion of the program. Database updates will only be performed if anomalies are detected.

5.6.5 Program 6172: CRIMP2—Cycle 5 Condensed-Regimen Integrated Monitoring Program for Side 2 of the GHRS

Purpose: The program monitors the sensitivity, wavelength and detector calibrations of Side 2 at a rate of 4 times per year.

Description: 4 times per year, the following observations will be done:

*   Detector calibrations:
    1) dark count measurement.
    2) focus check at nominal high voltage and tweak current.
    3) flat field exposure at center of photocathode.
    4) coarse sample mapping function at central y deflection.
    5) coarse line mapping function at central x deflection.
*   Sensitivity monitoring:

    The sensitivity calibration will be monitored with the UV spectrophotometric standard star BD +28°4211. The medium resolution gratings will measure the standard through the LSA and SSA. 5 observations will be made between 1200 and 3000 Å.
*   Wavelength monitoring:

    The spectral cal lamp mini-functional test for the first order gratings will be done. It is an internal test which makes measurements of the lamp (SC2). It is used to monitor the carrousel function, Y deflections, resolving power, and sensitivity.

Instrument Configuration:

SAFE2: RAPID,PHOTOSCAN;

G160M: ACCUM;

G200M: ACCUM;

G270M: ACCUM.

GO Programs Supported: GHRS programs using gratings G160M (31%), G200M (12%), and G270M (26%).

Time needed: Total of 44 orbits. 11 orbits per execution.

Special Requirements: As for CRIMP1.

Accuracy: As for CRIMP1 (6171).

Products: The results of the test will be documented in an *Instrument Science Report*. The ISR will be published 2 months after completion of the program. Database updates will only be performed if anomalies are detected.

5.6.6 Program 6209: Cycle 5 G140L Photocathode Granularity Determination

Purpose: To obtain a flat field for the G140L grating over a range of photocathode positions.

Description: The object of this program is to map artifacts on the surface of the photocathode due to granularity for the G140L grating. Locations of anomalous areas of the photocathode response will be determined by obtaining spectra of standard star HD93521 centered in the LSA and the SSA. The GHRS will be commanded in WSCAN mode and a series of spectra will be obtained from different positions on the digicon faceplate, the photocathode. This program need only be executed once at the start of Cycle 5.

Instrument Configuration: Side 1, G140L, LSA & SSA

GO Programs Supported:40 GHRS Cycle 5 programs (about 44%).

Time needed: 4 orbits.

Accuracy: The G140L flat field is needed to remove the effects of instrumental blemishes (small scale irregularities on the detector face plate and photocathode) from spectra with reasonable signal-to-noise (S/N ~50). The flat field will allow observers with good S/N to achieve 2% photometric precision for their data.

Products: The results for this program will be documented in an *Instrument Science Report* (ISR) and published after completion of the program. The flat field will be delivered to CDBS for delivery to OPUS.

5.6.7 Program 6210: GHRS Scattered Light Test–Cycle 5

Purpose: To measure of the scattered light within 3 arcsec of the GHRS Small Science Aperture.

Description: The object of this program is to measure the PSF from a point source in the SSA at various distances from the SSA. Thus, this is a combination PSF/scattered light test in that we measure the PSF at several different radii and at the same time obtain a measure of the contributed scattered light from nearby objects. This test will be carried out at two wavelengths, 2250 Å and 3050 Å, and will be used in conjunction with an SMOV test at 1450 Å to characterize the scattered light for GHRS.

This program need only be executed once during Cycle 5.

Fraction of GO Programs Supported: This test will be used for close-out and archival purposes and supports some Cycle 5 GO programs as well.

Time needed: External–4 orbits

Special Requirements: None.

Accuracy: The accuracy goal of this test is 2% absolute for each measured point in the PSF.

Products: The results for this program will be documented in an ISR and published within 2 months after completion of the program.

5.6.8 Program 6212: GHRS Cycle 5 G140M Sensitivity Characterization

Purpose: To determine the sensitivity and vignetting for grating G140M.

Description: This program observes a standard star to measure the sensitivity of G140M over its full wavelength range. Spectra are obtained with overlapping centers to make it possible to determine vignetting as well. The standard star m Col is observed with both the LSA and SSA in WSCAN mode. This program is to be executed only once at the start of Cycle 5.

Instrument Configuration: Side 1, G140M, LSA & SSA.

GO Programs Supported: 15 Cycle 5 GHRS programs (about 17%).

Time needed: 3 orbits.

Accuracy: Sensitivities are accurate to about 10% on an absolute scale. We will monitor G140M sensitivity in the future as well.

Products: The results from this program will be documented in an *Instrument Science Report* approximately 12 weeks after the observations are obtained. Calibration reference files will be delivered to OPUS at that time.

5.6.9 Program 6213: GHRS Aperture Offsets—Cycle 5

Purpose: The purpose of this test is to measure the relative wavelength offset between the LSA and SSA apertures for all gratings.

Description: While measurements of the relative offsets between SC1/SC2 and the SSA were made prior to launch, no such measurements were made for the LSA. During OV/SV some measurements were obtained but they provided minimal results for the Side 2 first-order gratings only. While it has always been recommended that observers use the SSA to obtain the best wavelengths, this test will provide LSA observers with better pipeline-calibrated wavelengths for their observations.

The strategy is to observe at a series of carrousel positions across each grating (order) in the LSA and SSA, taking a WAVECAL spectrum before each object spectrum. The wavelength coverage is needed as the pre-launch calibrations were found to vary non-linearly with wavelength. Exposure times are the minimum exposure time for the default STEPPATT which should give a minimum signal-to-noise of about 20.

This test will execute once during Cycle 5.

Fraction of GO Programs Supported: This test supports all LSA observations.

Time needed: External–16 orbits.

Special Requirements: None.

Accuracy Requirement: 1 diode RMS for wavelengths in the LSA.

5.7 Calibration Status

The following paragraphs summarize calibrations for the GHRS as of May, 1995. Some items are not applicable to a particular mode ("N/A") and some are to be measured in Cycle 5 ("TBD").

5.7.1 Detector Calibrations

Paired-pulse correction, diode response, and photocathode blemishes have been determined for both detectors. Photocathode response (flat fields) will not be measured, except for G140L (in Cycle 5).

5.7.2 Sensitivity

Absolute sensitivity and vignetting have been measured for both the LSA and SSA for G140L, Ech-A, G160M, and G270M. These have also been done for G200M and Ech-B except that LSA vignetting is TBD for G200M and SSA vignetting is TBD for Ech-B. G140M will be characterized completely in Cycle 5.

Scattered light and blaze functions have been determined for both Ech-A and Ech-B.

5.7.3 Wavelength

Line and sample mapping have been done for both detectors and thermal constants have been determined for all the gratings, as have global wavelength coefficients. Incidence angle corrections are available for G160M, G200M, and G270M, but are TBD for the remaining gratings.

Chapter 4	*Your Phase II Proposal and Using RPS2*

This version of the GHRS *Instrument Handbook* is for Cycle 6 users but is being written just after Phase II submissions for Cycle 5, and so these comments will reflect that experience. This chapter supplements the *Phase II Proposal Instructions* that will be issued for Cycle 6. The tool you will use for your Phase II proposal, RPS2, provides a precise and accurate estimate of the time needed to carry out various instrument functions with *HST*, but its instructions must be correspondingly precise and accurate. We begin this chapter with general remarks on GHRS usage, with specifics to follow.

Most users of the GHRS will find that a simple sequence of commands will work most of the time to obtain the data they desire:

- ACQ in LSA with BRIGHT=RETURN.
- ACQ/PEAKUP to center star in SSA if that aperture is used for the science observations that follow.
- IMAGE, if you wish to obtain an image of the object.
- Wavelength calibration exposure, if desired.
- ACCUMs at wavelengths of interest.
- ACQ/PEAKUP in the SSA if the previous observation was in the LSA.
- ACCUMs for that different aperture.
- Repeat the above as needed for more stars or more Visits.

The following sections describe each of these steps in more detail. At the end of the chapter we have provided several illustrative examples.

4.1 Acquisitions

Most objects observed with the GHRS are point sources (stars), and the majority of the remainder can be observed by first centering on a nearby point source and then offsetting to the object of interest. Point sources with accurate coordinates are very, very easy to acquire with the GHRS: just specify ACQ with BRIGHT=RETURN to have the instrument automatically center on the brightest object found within the LSA.

Target acquisitions always take place with the LSA because the SSA is too small to enable a field to be mapped effectively. Additional ACCUMs may be specified after the first so as to obtain spectra at several wavelengths.

4.1.1 Initial Pointing

A blind pointing with *HST* is likely to place the object of interest within 1 arcsec of the center of the Large Science Aperture if guide stars are used, and within about 10 arcsec if the pointing is done on gyros. That 1 arcsec accuracy is limited in part by the quality of coordinates provided by users and partly by errors in the positions of the FGSs relative to the GHRS apertures (see the *FOS Instrument Handbook* for a discussion of pointing errors). Using J2000 coordinates tied to the GSC reference frame can help to reduce the possibility of a failed acquisition. And don't forget to include proper motions if appropriate and to check the equinox and epoch of proper motions (see the *Phase II Proposal Instructions*).

4.1.2 Onboard Acquisitions

After the initial pointing, a GHRS onboard target acquisition begins with a spiral search centered on the field of view. The motions are made by the telescope, and at each point of the search either a single flux measurement (with 8 science diodes) or a map of the LSA is made. The default is a 3 × 3 pattern (SEARCH-SIZE=3) of maps in a square 4.6 arcsec on a side. Other options available are a 5 × 5 pattern (SEARCH-SIZE=5), 7.7 arcsec on a side, or a single integration (SEARCH-SIZE=1) that is 1.74 arcsec square (this latter option can be useful for obtaining a MAP after an object is centered). The telescope motions are made in the x and y coordinate system of the GHRS with a step-size of 1.53 arcsec. The motions are *not* in the U2, U3 system of the telescope.

For stars with good coordinates, the default (3 × 3) acquisition strategy will suffice (we are unaware of any acquisition failures in the recent past because of a too-small search area). In a few cases the 5 × 5 pattern guards against minor coordinate uncertainties (the time needed increases in proportion to [SEARCH-SIZE]^2, but the STEP-TIME for an acquisition is often so low that the total time involved is small).

You should use ONBOARD ACQ whenever:

- The object is a point source, or

- The object can be reached by offsetting from a nearby object that meets the above description, or

- An extended object is small enough that LOCATE=EXTENDED will work (see Section 4.1.4.4 on page 41).

Also, the object to be centered should be the brightest object within the area searched (with some allowance for uncertainty in positioning as well). In other words, you should ensure that your object is the brightest one that *HST* will find within a box whose total size is about 6 × 6 arcsec (this size differs from the 7.7 arcsec square box mentioned above to allow for uncertainty in position). Note that the flux is measured in the ultraviolet (see Section 7.4.1 on page 92).

The items you must specify for the ONBOARD ACQ are:

- The mirror to use. N2 and N1 will work for most targets. Mirror N2 provides a flat reflectivity over a broad range of ultraviolet wavelengths (see Section 7.4.1 on page 92). Mirror A2 has a similar spectrum response but reflects much less light than N2, in order to acquire bright objects. You may specify mirror N2 for an acquisition to observe with Side 1; this may be desirable, for example, when observing cool stars. However, doing this will cost the time needed to activate D1 after shutting down D2 since both detectors may not be fully on at the same time.

- In almost all cases you should specify BRIGHT=RETURN, which is a feature that automatically centers the brightest object found. If BRIGHT=RETURN is specified, any FAINT limit given is ignored. Explicit BRIGHT and FAINT flux limits may also be used instead, but there is rarely a reason to do so because BRIGHT=RETURN is so robust (see Section 7.5.2.1 on page 95 for more information).

- The size of the spiral search pattern to execute (SEARCH-SIZE). The default is a 3 × 3 grid (which covers about 4.6 arcsec square), but you may also request a 5 × 5 search over a square 7.7 arcsec on a side.

- Whether or not to record a map of the field at the search points so that you can confirm the telescope's pointing after the fact. The LOCATE phase of an acquisition precisely centers the object in the LSA. The residual pointing uncertainty after the LOCATE (or, equivalently, a PEAKUP), is two deflection steps, which is 0.054 arcsec. A MAP is therefore unnecessary and not an effective use of spacecraft time. At most, a MAP=END-POINT should suffice. (See Section 7.5.3 on page 95 for a discussion of MAPs.) Note that such a MAP occurs after the return to the brightest point in the field but *before* the object is centered in the LSA by an ACQ/PEAKUP. To determine the position of an object in the LSA before spectroscopic observations are begun, we recommend obtaining an IMAGE as a separate exposure line. The MAP=ALL-POINTS option may *not* be used with an ONBOARD ACQ.

- Any offset to apply once the object is centered (if appropriate).

4.1.3 Peakups

After the initial acquisition, a peakup helps to precisely center the object in the aperture. Specifying an ACQ/PEAKUP before starting LSA observations is redundant (a peakup is done as part of the LOCATE phase of an ACQ) and unnecessary. However, an ACQ/PEAKUP before starting SSA observations is vital for achieving the best throughput with the small aperture. In general, you should use the same STEP-TIME for a PEAKUP that you used for the ACQ, or perhaps a slightly longer STEP-TIME if the total number of counts is low (see page 44).

4.1.4 Onboard Strategies for Special Situations·

4.1.4.1 Side 2 Acquisitions for Side 1 Science Observations

There are situations in which an object can be observed satisfactorily with Side 1 but for which the count rates for acquisition mirrors N1 or A1 are extremely low. One possibility is to increase the exposure time for the acquisition, but the maximum permitted STEP-TIME is 12.75 seconds. A better option may be to acquire with mirror N2. Because both detectors, D1 and D2, may not be active in the GHRS at the same time, and there is a 40-minute overhead involved in making one primary and the other secondary; e.g., to go from Side 2 to Side 1. Whether or not that is a "cost" or not to your program depends on specific details. It is often the case that an acquisition takes place over the first orbit, followed by science observations in later orbits. In that case, much of the 40 minutes can take place during the part of the orbit when the target is inaccessible. But for CVZ viewing or single-orbit visits the cost can be real.

4.1.4.2 Complex Targets

Given the centering algorithm for the GHRS, which we will now describe, you can usually predict the results of an onboard target acquisition. Stepping, in both the x and y directions, is done in 0.027 arcsec steps, and on a point source the centering is expected to be good to within two steps. If the target is extended enough that the fluxes in the areas which are compared do not change significantly when a step is made, the centering accuracy will be degraded. An example is the case in which there is more than one source of light within the LSA.

Consider, for instance, two stars which are separated by 1.0 arcsec and for which the second star is 1 magnitude fainter than the primary star. Exact results will depend on the position angle between the two stars. The x balancing algorithm begins by placing the brightest source on the fourth of the eight diodes that are used during an acquisition (the LSA is imaged onto eight diodes), and moving until the flux on diodes 4 and 5 is balanced. The second star would not affect this balance at all unless its light fell on one of the same diodes as the primary star. In that case it would affect centering by a fraction of a diode.

In the y direction the results are different. If the second star is "above" or "below" the primary, it will "pull" the centering in that direction. In the case described, an extra source of light 40% as bright as the primary would be present in the upper or lower half of the LSA. The flux-balancing algorithm would divide the primary image 70-30, rather than 50-50, with the image displaced towards the half of the LSA which did not contain the second star. In this case the centering error should be less than 0.1 arcsec. If the LSA acquisition were to be followed by a slew to the SSA, PEAKUP, and an observation, the primary object should be successfully centered and observed. More complicated images, or sources more similar in brightness may not be suitable for onboard acquisition. (Note that balancing in the y direction is done before the x direction is balanced.)

4.1.4.3 Acquiring Faint Targets with the GHRS or FOS

Sometimes a star may be so faint that geocoronal Lyman-α can interfere with an acquisition. Some guidance for when this may be a problem is provided in Section 7.4.2 on page 94. If it is, we recommend that you specify SHADOW as a Special Requirement on the acquisition line on your Phase II form. Doing so constrains the scheduling of your proposal, so SHADOW or LOW-SKY should only be requested when they are necessary.

Another way to acquire very faint targets reliably is to use the Faint Object Spectrograph. This can be especially useful for acquiring extragalactic objects to observe with grating G140L because the acquisition mirrors for Side 1 of the GHRS reflect only far-ultraviolet light and because the maximum permissible integration time per dwell point is only 12.75 seconds. FOS-assisted acquisitions for the GHRS have been tested and have been found reliable once the object has been acquired with the FOS blue side. It is possible in principle to acquire with the FOS red side and then move the target to the GHRS (the relative positions are precisely known), but the overall motion is about 2.5 arcmin. The same guide stars must be used for both the FOS and GHRS portions of your program, but it is unlikely that guide stars will exist that can move 2.5 arcmin without leaving the FGS field of view (the "pickle"). Only in very special situations will it be possible to find guide stars that stay within the fields-of-view of the FGSs from beginning to end of this operation, and such guide stars are especially scarce at high Galactic latitude.

See Example 2 on page 52.

4.1.4.4 Acquiring Extended Sources with the GHRS

There are three classes of extended sources we can consider:

- Objects larger than the LSA that have roughly uniform surface brightness.
- Objects smaller than the LSA with roughly uniform surface brightness.

- Objects with significant structure, some of which is on scales smaller than the LSA.

The first class might be typified by Jupiter, and such objects are impossible to acquire directly with the GHRS because there is no clear photometric "center" to align on. In such cases it is necessary to offset from a smaller object which can be centered.

The second class of objects includes the Galilean satellites of Jupiter, and it is these for which the LOCATE=EXTENDED acquisition option was written. In a normal LOCATE, the object to be observed is moved in the *x* direction until the signal seen by the center two diodes (of the eight onto which the LSA is imaged) is balanced. LOCATE=EXTENDED in ACQuisition mode balances the four left diodes against the four right-hand ones to roughly center an object. In ACQ/PEAKUP mode, the EXTENDED option allows you to specify that the balancing be done over the central four, six, or eight diodes (specified as EXTENDED=2, 3, or 4).

The third class of objects can be the most problematic, especially if the target is an extragalactic one at high latitude. In such cases there may be no nearby star from which you could offset, but the source itself often contains point-like sources that can be centered on; in these cases an early acquisition or a pre-existing image is invaluable. The problem is then one of predicting acquisition count rates; that is treated in Section 7.1 on page 82. You may also wish to consider an acquisition with the FOS, as described in the previous section.

4.1.4.5 Offsetting

Even if an ONBOARD ACQuisition will not work for your target, it may still be possible to acquire a nearby offset star and to then offset to your target. Such an offset will happen automatically if the coordinates given for an acquisition exposure are different from those given for the science exposure. You would normally use two or three lines in the Phase II proposal to achieve this: acquisition of a offset star, offset, peakup on the target (if desired), and a science observation. The first line would request an onboard acquisition of the offset star. It should specify the Special Requirement ONBOARD ACQ FOR <line 2>. Line 2 would then specify the observation of the science target. A PEAKUP in the SSA could also be added if appropriate, but whether it was done on the offset star or the science target would depend on the brightness of the target and any crowding in the field being observed.

You must, of course, include the offset star as one of the objects on your target list. It should be designated *xxx*-OFFSET, where *xxx* is the name of the target object. If desired, you may give the position of your target by using RA-OFF, DEC-OFF, or XI-OFF, ETA-OFF and FROM relative to the offset star. See the *Phase II Proposal Instructions* for details and notes on proper units. In the Phase II proposal, the Target Name for line 1 is *xxx*-OFFSET, and in the example above, the Target Name for lines 2 and 3 is *xxx*.

To make a successful offset, the relative positions of the offset star and target must be very well known — about as well as 1/4 the size of the aperture. (e.g., rms errors of 0.05 arcsec for the SSA.) One way of obtaining such positions is by requesting an early acquisition WFPC2 image, and measuring relative positions from it (at least 2 months prior to the science observation). The offset positioning accuracy of the *HST* is expected to be very good (of the order of 0.03 to 0.05 arcsec for a 30 arcsec offset), and the accuracy of the placement will be primarily determined by the accuracy of your positions.

An offset of more than 30 arcsec may require the telescope to acquire new guide stars, which would worsen the accuracy of the positioning.

4.1.5 Acquisitions and RPS2

Very bright objects may need to be acquired with one of the attenuated mirrors, A1 or A2. Such acquisitions will take substantially longer than if N1 or N2 were used because of internal calibrations that are performed to determine the location of the aperture on the photocathode (the DEFCAL, or deflection calibration). In some cases you may wish to use N1 or N2 even if the object is bright as long as your object is not a threat to the GHRS. Very high count rates lead to a non-linear detector response, but that may not matter as long as the search algorithm can accurately determine where the center of the stellar image is.

Omitting the ONBOARD ACQ FOR Special Requirement from an acquisition can make it seem as though the ACQ takes less time. What is really happening is that without this Special Requirement the LOCATE phase of the acquisition is not being done. That saves time but results in poor centering, and we recommend using LOCATE.

Use the ONBOARD ACQ FOR Special Requirement to indicate the relationships between exposure lines. The general idea is that an ONBOARD ACQ is either done to prepare for a series of science observations (probably ACCUMs) or for a peakup. If an acquisition passes control to a peakup, then it should say ONBOARD ACQ FOR 20, say, where 20 is the line number of the peakup. But if the acquisition or the peakup is the last line before the science starts, then it should say ONBOARD ACQ FOR 20-60, or whatever the range of line numbers is that it pertains to.

4.1.6 Acquisition Parameters — A Summary

Step 1: Mode=ACQ

- Aperture should always be LSA ("2.0").

- MIRROR is usually N2 or N1 unless object is too bright (then use A2 or A1; see Section 7.1 on page 82). It is permissible to acquire with one side (mirror N2, say) and observe with the other (grating G140L, perhaps), but with a cost in time.

- SEARCH-SIZE=3 is the default and adequate almost all the time. Values of 1 or 5 may also be used.

- BRIGHT=RETURN is the default for finding the target and should be used unless you are forced not to. Do not specify FAINT unless you must specify an explicit BRIGHT limit. (FAINT is ignored if BRIGHT=RETURN is used.)

- LOCATE: Default is YES for an ONBOARD ACQ and NO for an early acquisition or INT ACQ. We recommend these defaults. Note that LOCATE=EXTENDED is now available. With an ONBOARD ACQ, LOCATE=NO may be used only if MAP=END-POINT is specified.

- MAP: (See Section 7.5.3 on page 95.) No image is generated by default for an ONBOARD ACQ. However, MAP=END-POINT will provide one if the target is in the LSA, but it will be made before the target is centered. If you wish to determine the actual position of the object in the LSA before spectroscopic observations are

begun, you should obtain an IMAGE as a separate exposure line, and you should *not* specify a MAP at all. MAP=ALL-POINTS may not be used with an ONBOARD ACQ.

- The time per exposure can be calculated from:

$$t_{exp} = (\text{SEARCH-SIZE})^2 \times \text{STEP-TIME},$$

where the SEARCH-SIZE is 1, 3, or 5. If you use the MAP option, refer to Section 7.5.3 on page 95 to calculate the exposure time. **Please note the value of STEP-TIME you want as a COMMENT on the exposure line.**

- Special Requirement is ONBOARD ACQ FOR <exp list>.

Step 2: Mode=ACQ/PEAKUP

- In general, use PEAKUP only for SSA observations; it is unnecessary for the LSA. However, formally the aperture can be specified as either the LSA ("2.0") or SSA ("0.25"); use the one that will be used for the science observations that immediately follow.

- Specify the MIRROR as for Mode=ACQ; i.e., N1, A1, N2, or A2 depending on target brightness.

- The time per exposure can be calculated from

$$t_{exp} = f_{Aperture} \times \text{STEP-TIME}$$

where $f_{Aperture} = 102$ if the LSA is used and $f_{Aperture} = (\text{SEARCH-SIZE})^2$ if the SSA is used. Note that the throughput of the SSA is half to 2/3 that of the LSA so that you may wish to specify a longer STEP-TIME if the overall counts accumulated are small. The default SEARCH-SIZE for the SSA is 5.

- We urge you to be precise and explicit about the way in which you specify an ACQ/PEAKUP and the order in which observations are to be made. The defaults that apply to ACQ and ACQ/PEAKUP modes will usually accomplish what you wish, but the way to be sure is to specify the details. Confusion can arise particularly when a program mixes LSA and SSA observations. We recommend that you do an ACQ on the first line of your exposures, then on line 2 specify ACQ/PEAKUP if SSA observations follow and indicate the lines to which the PEAKUP applies (all of which should use the same aperture). Then specify another ACQ/PEAKUP before starting observations in the other aperture.

- Special Requirement is ONBOARD ACQ FOR <exp list>.

- Please note the STEP-TIME to be used as a comment.

4.1.7 Other Acquisition Parameters

There are other types of acquisitions – interactive and early – that have not been used by anyone for some time because strategies using ONBOARD ACQs work and are more efficient. Also, the ability to get MAPs is now little used. These parameters have been moved to the end of Chapter 7 (see Section 7.5 on page 94) to simplify this chapter.

4.2 Image Mode

The GHRS is, of course, primarily a spectrograph, but it includes useful imaging capabilities, especially because the detectors of the GHRS are blind to much of the visible light that dominates the flux of most stars. You may wish to request an IMAGE, for example, to confirm that the telescope had your object properly centered in the data-taking aperture before the exposure was taken.

Note the following in using the imaging capability:

- GHRS IMAGEs and MAPs are obtained with the focus diodes (see Section 6.3 on page 76) at the ends of the array of main science diodes. The focus diodes are smaller and square, making them more useful for focusing, but at the price of a lower count rate. The total count rate over the LSA is, of course, unchanged, and it is that which is predicted with the information in Section 7.1 on page 82. Multiply the count rate estimated for the regular diodes by approximately 0.3 to get the value appropriate to the focus diodes when they are centered on the star.

- A MAP is obtained as an integral part of an acquisition whereas an IMAGE is a separate observation that may or may not have anything to do with an acquisition. A MAP with SEARCH-SIZE=3 or 5 is made as the acquisition procedure causes the telescope to make small motions in a square spiral pattern, thereby enabling it to record a larger portion of the sky than the LSA itself subtends. An IMAGE can only record the light in the 1.74 × 1.74 arcsec region of the LSA. A single MAP (SEARCH-SIZE=1) is equivalent to an IMAGE. Note that MAP=ALL-POINTS may not be used with an ONBOARD ACQ.

- A standard IMAGE will have a pixel spacing of 0.109 arcsec and will cover the entire LSA aperture of 1.74 × 1.74 arcsec. You may also select pixel spacings of 0.055 or 0.027 arcsec, with proportionately smaller regions of the sky covered in a 16 × 16 (the default) IMAGE. You may also use IMAGE with the SSA.

- The PSF of the GHRS is not simple nor has it been well-studied. If you need high-quality imaging, we recommend that you consider the FOC or WFPC2.

4.2.1 Image Mode Parameters

- Either the LSA ("2.0") or SSA ("0.25") may be selected as the aperture. The SSA is so small that it is generally pointless to image it, although there may be special cases where IMAGE mode is of use, particularly for confirming pointing in a crowded field.

- A mirror is the usual choice as optical element. A grating may also be specified – see below.

- The number of pixels in the x and y directions can be chosen separately and can range from 1 to 512 pixels. However, a large number of pixels only oversamples the region of sky subtended by the LSA and does not make the IMAGE include a larger area. The parameters to specify are NX, NY, DELTA-X, and DELTA-Y, for which the defaults are 16, 16, 4, and 4, respectively. The product of NX and NY may not exceed 512. An image that is critically sampled in the x direction may be obtained by specifying NX=32, NY=16, DELTA-X=2, and DELTA-Y=4.

Only the N1 mirror intercepts the full beam diameter, meaning that images of the LSA with the other acquisition mirrors will not yield an accurate Point Spread Function (PSF).

- The PRECISION parameter may be specified as NORMAL (the default) or HIGH. PRECISION may only be specified if DELTA-Y=4. Using PRECISION=HIGH causes the image to be obtained with only one focus diode instead of two, thereby eliminating uncertainty over the relative response of the two.

- There are two focus diodes available to raster over the LSA. Thus the total time needed is the dwell time per pixel (0.2 seconds is the default) times the number of pixels in the x direction (default is NX=16) times the number of y pixels (default is NY=16), all divided by 2. The maximum permissible dwell time per pixel is 12.75 seconds.

4.2.2 The GHRS as a Slitless Spectrograph

In IMAGE mode you may specify a grating instead of a mirror as the spectrum element (note that this may *not* be done in Acquisition Mode). Doing so for a target that emits primarily in lines can yield the equivalent of using a slitless spectrograph over a very small portion of the sky (the 1.74 arcsec square region of the LSA). Thus the focus diodes would be swept over the image of the line to produce a picture that is resolved spatially in the y direction and spectroscopically in the x direction. This mode of use would be very slow if all you wanted was the spatial structure of a small object (the FOC would probably be better), but there might be interesting uses for obtaining spectrophotometrically pure, spatially resolved images in the ultraviolet. Please consult us if you wish to explore this option.

4.3 Accumulation Mode

The previous chapter provided the information needed to estimate an exposure time to achieve a given level of signal-to-noise. We reiterate several factors having to do with the detectors that must be taken into account to achieve the best data quality. Note that it is not necessary to explicitly specify these parameters (except for FP-SPLIT) because the defaults that apply to each mode of operation will automatically invoke them. Moreover, you should not deviate from the defaults without good reason.

The Digicon detectors have faceplates with some granularity (uneven response). The diodes onto which the faceplate is imaged also have response irregularities and some of them have been turned off because of misbehavior. Both of these effects are relatively small but enough to prevent you from obtaining a spectrum with S/N much in excess of about 30. They can also produce "glitches" that can mimic spectrum features. The FP-SPLIT parameter causes the carrousel to move slightly between each of the two or four separate subexposures (depending on the value you choose). The COMB parameter suppresses diode-to-diode gain variations and allows one to work around the dead diodes. Both features should normally be used, especially since they cost little or nothing in exposure time and improve data quality.

The Digicon diodes also undersample the spectrum by about a factor of two. The parameter STEP-PATT causes electronic motions of the spectrum so as to sample the spectrum fully. It is possible to STEP-PATT at two samples per diode width, but we

recommend using four samples per diode to yield optimum results, and again at no net cost. You can always rebin a quarter-stepped spectrum into a half-stepped one during your data analysis, but the process cannot make a quarter-stepped spectrum out of a half-stepped one. Deconvolution has worked best with quarter-stepped spectra (the default); see Gilliland et al. (1992). STEP-PATT also determines the way in which the background is measured (see Section 8.3 on page 106).

We also remind you to break up long exposures into subexposures that are no longer than about 5 to 10 minutes each, so as to defeat the effects of geomagnetically-induced image motion. Bear in mind that a 20 minute exposure, for example, specified with FP-SPLIT=4 will result in four 5-minute exposures.

4.3.1 Wavelength Calibrations

Remember to have wavelength calibration exposures precede the ACCUM to which they apply. This minimizes the time interval between these two exposures, so that wavelength drifts do not occur. Use SEQ <exp list> NON-INT as a Special Requirement to make sure the two lines as a group are not split.

Wavelength calibration exposures cannot ordinarily be scheduled during Earth occultation. The reasons have to do again with the interruptibility of GHRS exposures and the fact that the sequence of exposures that actually executes bears only a casual resemblance to what RPS2 shows you due to SAA passages. In a few cases we have executed WAVE exposures during occultation, but the manual effort needed is substantial, meaning that the science requirements have to be unusual and demanding.

There are calibration exposures made called SPYBALs that can often substitute for a WAVE exposure. A SPYBAL is an exposure of the wavelength calibration lamp, but it is made at a fixed setting for each grating as a means of centering the spectrum on the diodes in the direction perpendicular to dispersion (SPectrum Y BALance). Your WAVE exposure, on the other hand, would be made at the specific wavelength you're observing at. Clearly the latter is superior, but in many cases the SPYBAL exposure contains enough information to correct the wavelength zero point of your spectrum very nearly as well as the WAVE exposure would have.

SPYBALs are executed every time a new grating is used and about once every other orbit thereafter (the details of the thereafter depend on how you write your exposure lines and are impossible to generalize about). Sometimes an observer wishes to ensure that the grating carrousel is not moved at all until they have done all their exposures at a particular setting. That can be achieved with SPYBAL=NO. However, the defaults almost always provide satisfactory results.

4.3.2 Memory Usage

A problem can arise when a science program specifies a large number of separate GHRS exposures. This problem is caused by the relatively small amount of memory available on *HST* in which to store GHRS commands. It is usually possible to break up such a program into several visits so that the separate exposures are not all together, but occasionally the science goals cannot allow that and some other compromise must be made. Roughly speaking, about 40 total spectra can be scheduled in a single visit (a WSCAN with *n* set-points counts as *n* exposures and an FP-SPLIT counts as 2 or 4).

Once that number is exceeded the remaining observations must be scheduled in a new visit, and that means a new target acquisition will be needed, with the resultant overhead time. Using a large number of iterations in an ACCUM does *not* cause a memory problem, but what does is lots of *different* instrument settings.

4.3.3 Summary of Accumulation Mode Parameters

- Specify the aperture as "2.0" (LSA) or "0.25" (SSA). The object will automatically be moved to the correct aperture even if the acquisition was into the other aperture. If a SSA spectroscopic observation follows an LSA spectroscopic observation, we recommend an ACQ/PEAKUP in the SSA with SEARCH-SIZE=5 before beginning an ACCUM.

- If wavelength accuracy is needed that exceeds the default (see Section 5.3 on page 59), then specify WAVE as the target with an aperture of SC2. Specify a WAVE *before* the ACCUM to which it applies.

- Specify the grating to be used, either first-order or echelle. If you wish to force an echelle observation to be done in an order other than the default, you may do so by specifying the grating as, for example, ECH-B24, where 24 was the order chosen.

- STEP-PATT may be chosen as a number from 1 to 15, and specific pattern numbers go with specific spectrograph configurations. We recommend using the default that pertains to the setup you have chosen (STEP-PATT=DEF). The details of how the substepping is performed and the background measured are given in Section 8.3 on page 106.

- FP-SPLIT=STD is recommended if you hope to achieve a signal-to-noise level of about 30 or better. The default for FP-SPLIT is NO, which will *not* yield a spectrum with the best signal-to-noise. However, restoring your observations to their full spectroscopic resolution depends on having enough signal-to-noise in each individual subexposure to achieve a satisfactory cross-correlation. In other words, you should not rely on a priori knowledge of carrousel position to shift the individual FP-SPLIT exposures back to a common wavelength zero point. For this reason you should probably not use FP-SPLIT at all for signal-to-noise levels below about 30.

- COMB=FOUR is the default value and is recommended for the best results.

- Once you have chosen the STEP-PATT, note the minimum exposure time in the last column of Table 8-5 on page 107; this is the time it takes to go through one complete cycle of the pattern, and your total exposure time should be an integral multiple of this number. If you are using FP-SPLIT, however, multiply the cycle time by the FP-SPLIT value (2 or 4) to get the minimum exposure time. For example, STEP-PATT=5 is frequently used, and its minimum exposure time is 27.2 seconds (these values are based on using COMB=FOUR, which is recommended). If FP-SPLIT=STD is used, the minimum time is 4 times 27.2, or 108.8 seconds. If you wished to spend about 20 minutes on an object, the exposure time to choose would be 1196.8 seconds, which is 11 cycles. If you specified a time of 20 minutes, the actual value used would be 1196.8 anyway, even if RPS2 makes it appear as if the full 20 minutes is used (this aspect of RPS2 may change by the time you prepare a Cycle 6 Phase II proposal).

- DOPPLER=DEF is recommended. This activates compensation for the velocity shifts of astronomical spectra over the course of an orbit but turns it off for internal exposures.

- STEP-TIME may be specified as a number from 0.2 to 12.75 seconds, in increments of 0.05 seconds. STEP-TIME specifies the length of the individual subspectra that are accumulated to form the final spectrum, and there is no good reason to not use the default of 0.2 sec.

- Specify Wavelength as the central wavelength (preferred) or wavelength range for the exposure, in Ångstroms.

- The CENSOR parameter may also be specified. The default is NO, which is appropriate in almost all cases. If CENSOR=YES is used, individual subspectra are examined onboard the spacecraft and are discarded if multiple counts have occurred within a 8 μs interval. This allows for the lowering of background noise in cases where the object being observed is very faint, i.e., less than about 0.1 counts per second per diode. Rejected exposures are repeated by the GHRS, leading to a longer total elapsed time for the observation, but only by about 2%. See Section 8.5.3 on page 110 for more information on CENSOR.

- A special commanding option called FLYLIM can also be used to reject noise in cases where the object is substantially fainter than the background. See Section 8.5.4 on page 112.

- If you have any doubts about the manner in which your program will be executed, we recommend that you remove the ambiguity by explicitly indicating all the Optional Parameters and Special Requirements.

4.3.4 WSCAN and OSCAN modes

Use of WSCAN can result in a spectrum covering a broader total bandpass than is possible with a single exposure. All the parameters listed above for an ACCUM exposure are available in WSCAN mode. The most important parameter to specify is WAVE-STEP, which is the spacing (in Ångstroms) between each subexposure. If WAVE-STEP=DEF is specified, the central wavelengths of the separate exposures will be equally spaced so as to cover the range of wavelengths that you specify, with at least 20% overlap from one subspectrum to the next.

You may also explicitly give a WAVE-STEP value. If λ_{min} is the central wavelength of the shortest-wavelength exposure, and λ_{max} is the central wavelength of the longest-wavelength exposure, then choose these values in concert with WAVE-STEP so as to yield an integral number of WAVE-STEPs between λ_{min} and λ_{max}.

OSCAN mode makes it possible to scan across echelle orders at a fixed value of $m\lambda$, where m is the order number and λ is the wavelength. It is rare that adjacent orders both have features of astrophysical interest and so this mode is primarily used for calibrations and not for science observations. If you do use this mode, all the parameters of an ACCUM observation are available.

4.4 Rapid Readout Mode

This mode is sometimes referred to as Direct Downlink. A normal ACCUM exposure is the best way to get a good spectrum because all the features of the spectrograph are available to you: automatic compensation for the motion of the spacecraft along the line-of-sight, rejection of high-noise subspectra with CENSOR, use of FP-SPLIT, COMB, and STEP-PATT to optimize data quality, and so on. However, there are times when ACCUM cannot obtain successive spectra as quickly as is needed to probe a particular phenomenon.

In those cases you can use RAPID mode. The data are read from the detector at the end of each short integration, either to the science tape recorder on *HST* or through TDRSS to the ground. Data obtained in RAPID mode require special handling by the observer to correct for some of the effects (especially doppler shifts) that are automatically compensated for in ACCUM mode.

As for an ACCUM, you should specify the science aperture and the spectral element. You may also choose to observe WAVE as target to get a wavelength calibration. The only other parameter you may specify is SAMPLE-TIME, which is the length of each separate exposure that is read to the ground. The default SAMPLE-TIME is also the minimum, 0.05 seconds. SAMPLE-TIME may be incremented in 0.05 second values up to a maximum of 12.75 seconds. Use of a very short SAMPLE-TIME and/or use of RAPID mode for extended periods can cause scheduling problems because of the very high data volumes that are generated. In particular, a SAMPLE-TIME of less than 0.33 sec records data at the 1 Mb-rate and so can. proceed for no more .than about 20 minutes before filling the onboard tape recorder. A SAMPLE-TIME of 0.33 seconds or more results in a data rate that can be sustained for about 10 hours.

4.5 The Structure of Exposures within Orbits with RPS2

RPS2 gives you the means to predict many details of how your observations will be carried out. But there are also missing pieces because the actual scheduling software for *HST* – upon which RPS2 is based – is very complex. Thus RPS2 is an approximation. Perhaps the single most important thing to bear in mind when you look at your RPS2 output for a GHRS program is that RPS2 *assumes* your observations fall into tidy orbits with a nominal observing period and without being interrupted by the South Atlantic Anomaly (SAA). But in practice those assumptions are unlikely to pertain. The target visibility available at the time your observation is actually scheduled may be longer than what RPS2 showed you (it is unlikely to be shorter), meaning that an observation you thought was starting at the beginning of an orbit is now starting near the end of the previous orbit. That can change significantly some aspects of your program. Even more important, the GHRS is the only interruptible instrument now on *HST,* making it likely that your program will actually run over more orbits than those RPS2 shows you because of the interruptions caused by passages through the SAA. You can ask that your program avoid the SAA, but that should be reserved for specific science needs. (Note that the time you are charged is that calculated by RPS2, even if more time is actually needed when the program executes.)

In some programs requiring very high wavelength precision you will not want to have your exposures interrupted by SAA passage or earth occultation because that time delay adds uncertainty. To ensure these interruptions do not occur, specify NO SPLIT as a Special Requirement on those exposures. Do *not* use END ORBIT with the GHRS; it is not appropriate to an interruptible instrument. Note that using NO SPLIT causes all sub-exposures associated with a single exposure to be put together as a single unit and therefore inefficient use of your orbits can result.

4.6 Examples of GHRS Phase II Proposals

Example 1. An acquisition of a star into the LSA followed by an SSA peakup and two ACCUMs.

```
Visits
        Visit_Number: 1
Visit_Requirements: BETWEEN 5-MAY-1996 AND 8-JUN-1996
    Visit_Comments: Coordinated with ground observations.

      Exposure_Number: 1
         Target_Name: HD12345
              Config: HRS
              Opmode: ACQ
            Aperture: 2.0
          Sp_Element: MIRROR-N1
          Wavelength:
  Optional_Parameters: BRIGHT=RETURN,      ! These are the default
                       SEARCH-SIZE=3       ! parameters.
 Number_of_Iterations: 1
    Time_Per_Exposure: 13.5S
 Special_Requirements: ONBOARD ACQ FOR 2
             Comments: STEP-TIME = 1.5 sec

      Exposure_Number: 2
         Target_Name: HD12345
              Config: HRS
              Opmode: ACQ/PEAKUP
            Aperture: 0.25
          Sp_Element: MIRROR-N1
          Wavelength:
  Optional_Parameters: SEARCH-SIZE=5       ! Default
 Number_of_Iterations: 1
    Time_Per_Exposure: 37.5S
 Special_Requirements: ONBOARD ACQ FOR 3-6
             Comments: STEP-TIME = 1.5 sec

      Exposure_Number: 3
         Target_Name: WAVE
              Config: HRS
              Opmode: ACCUM
            Aperture: SC2
          Sp_Element: ECH-A
          Wavelength: 1404
  Optional_Parameters: SPYBAL=YES
 Number_of_Iterations: 1
```

```
      Time_Per_Exposure: DEF
     Special_Requirements:
               Comments:

        Exposure_Number: 4
            Target_Name: HD12345
                 Config: HRS
                 Opmode: ACCUM
               Aperture: 0.25
             Sp_Element: ECH-A
             Wavelength: 1404
    Optional_Parameters: FP-SPLIT=STD,  STEP-PATT=DEF
    Number_of_Iterations: 1
      Time_Per_Exposure: 870.4S
     Special_Requirements:
               Comments:

        Exposure_Number: 5
            Target_Name: WAVE
                 Config: HRS
                 Opmode: ACCUM
               Aperture: SC2
             Sp_Element: ECH-A
             Wavelength: 1640
    Optional_Parameters: SPYBAL=YES
    Number_of_Iterations: 1
      Time_Per_Exposure: DEF
     Special_Requirements:
     Comments:

        Exposure_Number: 6
            Target_Name: HD12345
                 Config: HRS
                 Opmode: ACCUM
               Aperture: 0.25
             Sp_Element: ECH-A
             Wavelength: 1640
    Optional_Parameters: FP-SPLIT=STD,  STEP-PATT=DEF
    Number_of_Iterations: 2
      Time_Per_Exposure: 1523.2S
     Special_Requirements:
               Comments:
```

Example 2. An acquisition with the FOS blue side followed by a GHRS ACCUM. Note the Special Requirement "SEQ 4-5 NON-INT" for exposure 4. This forces lines 4 and 5 to occur together. Also, because of the acquisition with the FOS, this NON-INT forces a SPYBAL to occur before the WAVE exposure, just as one would wish.

```
Visits

          Visit_Number: 1
     Visit_Requirements:
       On_Hold_Comments:
         Visit_Comments:
```

```
          Exposure_Number: 1
              Target_Name: NGC1234
                   Config: FOS/BL
                   Opmode: ACQ/PEAK
                 Aperture: 4.3
               Sp_Element: MIRROR
       Optional_Parameters: SEARCH-SIZE-X=1, SEARCH-SIZE-Y=3,
                            SCAN-STEP-Y=1.23
      Number_of_Iterations: 1
         Time_Per_Exposure: 1S
      Special_Requirements: ONBOARD ACQ FOR 2
                 Comments: FOS search pattern A


          Exposure_Number: 2
              Target_Name: NGC1234
                   Config: FOS/BL
                   Opmode: ACQ/PEAK
                 Aperture: 1.0
               Sp_Element: MIRROR
       Optional_Parameters: SEARCH-SIZE-X=6, SEARCH-SIZE-Y=2,
                            SCAN-STEP-X=0.61, SCAN-STEP-Y=0.61
      Number_of_Iterations: 1
         Time_Per_Exposure: 1S
      Special_Requirements: ONBOARD ACQ FOR 3
                 Comments: FOS search pattern B1

          Exposure_Number: 3
              Target_Name: NGC1234
                   Config: FOS/BL
                   Opmode: ACQ/PEAK
                 Aperture: 0.5
               Sp_Element: MIRROR
       Optional_Parameters: SEARCH-SIZE-X=3, SEARCH-SIZE-Y=3,
                            SCAN-STEP-X=0.29, SCAN-STEP-Y=0.29
      Number_of_Iterations: 1
         Time_Per_Exposure: 2S
      Special_Requirements: ONBOARD ACQ FOR 4-5
                 Comments: FOS search pattern C1

          Exposure_Number: 4
              Target_Name: WAVE
                   Config: HRS       ! switching to GHRS for science obs
                   Opmode: ACCUM
                 Aperture: SC2
               Sp_Element: G140L
               Wavelength: 1395
      Number_of_Iterations: 1
         Time_Per_Exposure: 1M
       Optional_Parameters: SPYBAL=YES
      Special_Requirements: SEQ 4-5 NON-INT
                 Comments: WAVECAL for exposure 5

          Exposure_Number: 5
              Target_Name: NGC1234
                   Config: HRS
                   Opmode: ACCUM
                 Aperture: 2.0
               Sp_Element: G140L
```

```
              Wavelength: 1395
     Optional_Parameters: STEP-PATT=5
    Number_of_Iterations: 3
       Time_Per_Exposure: 598.4S
    Special_Requirements:
                Comments:
```

Example 3. An IMAGE mode observation in the LSA followed by an ACCUM.

```
Visits
       Visit_Number: 1
Visit_Requirements:
    Visit_Comments:

       Exposure_Number: 1
          Target_Name: HD123
               Config: HRS
               Opmode: ACQ
             Aperture: 2.0
           Sp_Element: MIRROR-N2
           Wavelength:
  Optional_Parameters: BRIGHT=RETURN, SEARCH-SIZE=3   !Defaults
 Number_of_Iterations: 1
    Time_Per_Exposure: 1.8S
 Special_Requirements: ONBOARD ACQ FOR 2-4
             Comments: STEP-TIME=.2S


       Exposure_Number: 2
          Target_Name: HD123
               Config: HRS
               Opmode: IMAGE
             Aperture: 2.0
           Sp_Element: MIRROR-N2
           Wavelength:
  Optional_Parameters: DELTA-X=4, DELTA-Y=4,      ! Default parameters
                        NX=16, NY=16
 Number_of_Iterations: 1
    Time_Per_Exposure: 25.5S
 Special_Requirements:

       Exposure_Number: 3
          Target_Name: WAVE
               Config: HRS
               Opmode: ACCUM
             Aperture: SC2
           Sp_Element: G160M
           Wavelength: 1549
  Optional_Parameters: SPYBAL=YES
 Number_of_Iterations: 1
    Time_Per_Exposure: 1M
 Special_Requirements:
             Comments:

       Exposure_Number: 4
          Target_Name: HD123
               Config: HRS
```

```
             Opmode: ACCUM
           Aperture: 2.0
         Sp_Element: G160M
         Wavelength: 1549
Optional_Parameters: FP-SPLIT=STD,  STEP-PATT=DEF
Number_of_Iterations: 1
   Time_Per_Exposure: 1305.6S
Special_Requirements:
           Comments: C IV
```

Example 4. A combination of ACCUM and RAPID modes.

```
Visits
      Visit_Number: 1
Visit_Requirements: CVZ

     Exposure_Number: 10
         Target_Name: HD112233
              Config: HRS
              Opmode: ACQ
            Aperture: 2.0
          Sp_Element: MIRROR-N2
          Wavelength:
 Optional_Parameters: BRIGHT=RETURN,        ! Default  parameters
                      SEARCH-SIZE=3
Number_of_Iterations: 1
   Time_Per_Exposure: 15.75S
Special_Requirements: ONBOARD ACQ FOR 20-40

             Comments: STEP-TIME=1.75S; Expected  count  rate  =  525
counts/sec

     Exposure_Number: 20
         Target_Name: HD112233
              Config: HRS
              Opmode: ACCUM
            Aperture: 2.0
          Sp_Element: G270M
          Wavelength: 2815
 Optional_Parameters: FP-SPLIT=STD,  STEP-PATT=5
Number_of_Iterations: 4
   Time_Per_Exposure: 326.4S
Special_Requirements:
            Comments:

     Exposure_Number: 30
         Target_Name: HD112233
              Config: HRS
              Opmode: RAPID
            Aperture: 2.0
          Sp_Element: G160M
          Wavelength: 1293
 Optional_Parameters: SAMPLE-TIME=0.35,
                      SAA-CONTOUR=DEF
Number_of_Iterations: 1
   Time_Per_Exposure: 1200S
Special_Requirements:
```

```
       Exposure_Number: 40
          Target_Name: HD112233
                Config: HRS
               Opmode: RAPID
             Aperture: 2.0
           Sp_Element: G160M
          Wavelength: 1432
  Optional_Parameters: SAMPLE-TIME=0.35
 Number_of_Iterations: 1
    Time_Per_Exposure: 1200S
  Special_Requirements:
```

Design and Construction of the GHRS

6.1 The HST Focal Plane and the GHRS Apertures

We provide here a description of the instrument in largely pictorial terms. More illustrations and full technical descriptions of the GHRS may be found in the references (see Section 9.2 on page 116).

Figure 6-1. The Hubble Space Telescope and its components. The locations of important elements are shown.

Figure 6-2. The focal plane of HST and the definitions of the V2, V3, U2, and U3 axes in the coordinate system of the spacecraft.

Figure 6-3. Locations of GHRS apertures relative to spacecraft axes. Note that the sense of the x and y motions are shown by the arrows, but that the zero point for each aperture (LSA and SSA) is located at its center. COSTAR has not changed the layout of the entrance apertures, but it has altered the way in which the sky is imaged onto the focal plane. The sense of the change is that the signs of motion in both coordinates, V2 and V3 (or U2 and U3) are reversed.

Figure 6-4. Optical schematic of the GHRS.

6.2 Gratings and Optical Elements

Table 6-1   Properties of GHRS Gratings

Name	Grooves per mm	Blaze Angle	Order of use	Angle of Incidence	Diffraction Angle (degrees)	Deviation Angle (degrees)	Detector
G140L	600	2.6	1	9.0 – 10.3	−5.3 − −4.0	14.25	D1
G140M	6000	23	1	26 – 38	11 – 24	14.25	D1
G160M	4960	19	1	21 – 33	14 – 27	6.25	D2
G200M	4320	26	1	23 – 34	17 – 28	6.25	D2
G270M	3600	28	1	27 – 38	20 – 32	6.25	D2
Ech-A	316	63.4	33 – 53	68 – 74	54 – 61	13.25	D1
Ech-B	316	63.4	17 – 33	63 – 72	58 – 66	5.75	D2
CD-A	194.6	0.75	1				D1
CD-B	85.7	0.54	1				D2

Note that the "CD" gratings are cross-dispersers for the echelles. CD-A has a focal length of 1460 mm and CD-B has a focal length of 1340 mm. Note also that the "M" gratings are holographic and that the blaze angle quoted formally is that which correctly predicts the center of the wavelength region the grating is optimized for. G140L is a ruled grating. "Ech-A" and "Ech-B" refer to two modes of operation that use the same echelle grating but different cross-dispersers and detectors.

Table 6-2   Properties of Other GHRS Optical Components

Name	Clear Aperture (mm)	Focal Length (mm)	Detector
LSA = "2.0"	0.559		D1, D2
SSA = "0.25"	0.067		D1, D2
Collimator	80	1850	D1, D2
Mirror N2[a]	80		D2
Mirror A2	20		D2
Mirror N1	80		D1
Mirror A1	20		D1
Cam-A	84	1425	D1
Cam-B	86	1350	D2
D1	22 × 28		
D2	22 × 28		

a. Mirror N2 is actually "D" shaped, being a circle with a small slice off one side. It is about 60 × 80 mm.

Figure 6-5. Schematic diagram of GHRS acquisition optics. The "main acquisition mirror" is N2.

6.3 The Digicon Detectors

Figure 6-6. Cutaway view of a Digicon.

Figure 6-7. Cross-section of a Digicon and views of its faceplate and diode arrays.

Figure 6-8. A view from the cross-dispersers toward the Digicon detectors, to illustrate the senses of x and y motions and of increasing wavelength.

Figure 6-9. A detailed layout of the diodes in the Digicon detectors. Note the six large corner diodes and the six focus diodes (numbers 4, 5, and 6, for example).

Reference Information on Instrument Performance

8.1 Properties of the First-Order Gratings

8.1.1 Useful Wavelength Ranges

The following table summarizes the useful wavelength range for each of the first-order gratings of GHRS. More precise sensitivity values are enumerated below. Note that little or no flux below 1150 Å is reflected by the COSTAR mirrors because of their magnesium fluoride coatings.

Table 8-1   Useful wavelength ranges for first-order gratings.

Grating	Useful Range (Å)	Å per diode	Bandpass (Å)	Comment
G140L	1100 – 1900	0.572 – 0.573	286 – 287	
G140M	1100 – 1900	0.056 – 0.052	28 – 26	
G160M	1150 – 2300	0.072 – 0.066	36 – 33	2nd order overlap above 2300 Å
G200M	1600 – 2300	0.081 – 0.075	41 – 38	2nd order overlap above 2300 Å
G270M	2000 – 3300	0.096 – 0.087	48 – 44	2nd order overlap above 3300 Å

The "bandpass" column provides the number of Ångstroms per exposure one can expect, the range being from the blue end of the spectrum to the red.

The last three gratings are used with detector D2, which admits some second-order light, hence the comments. For example, Lyman-α light (1216 Å) can appear at 2432 Å in second order. Except for this possibility of geocoronal contamination, many cool stars have very little short-wavelength flux, so that the best resolution can be achieved without undue extraneous light by observing in first order near the high-wavelength limit.

Note that the G270M grating has an order-sorting filter which eliminates light below about 1650 Å so that no cross-order contamination occurs below 3300 Å.

8.1.2 Resolving Power

The following figures illustrate the resolving power as measured for each of GHRS' gratings. In this case the resolving power was computed as $\mathcal{R} = \lambda/\Delta\lambda$, where $\Delta\lambda$ is the measured full-width-at-half-maximum (FWHM) of lines from an exposure of a spectrum calibration lamp. Tests have shown that the measured FWHM does not change significantly with wavelength (for the first-order gratings) or with $m\lambda$, the product of the wavelength and order number (for the echelle gratings). The nominal design specification for the GHRS was $\mathcal{R} = 20,000$ for the first-order gratings, but in fact one can exceed a resolving power of 25,000 at virtually all wavelengths. Similarly, the low-dispersion grating G140L has R in excess of 2,000 over most of its useful wavelength range. The true resolving powers for the echelle gratings are closer to 80,000 than the nominal 100,000.

By providing a sharper image of a point source, COSTAR restores the resolving power achieved with the LSA to within about 20% of that possible with the SSA. There is no effective change for the SSA, however.
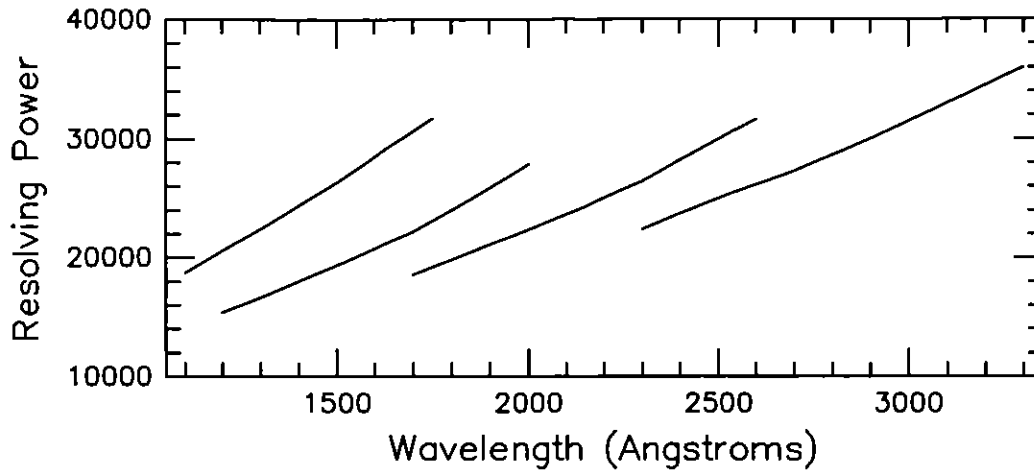
Figure 8-1. Spectrum resolving power as a function of wavelength for the GHRS medium-resolution (holographic) gratings. From left to right the curves are for G140M, G160M, G200M, and G270M, respectively.
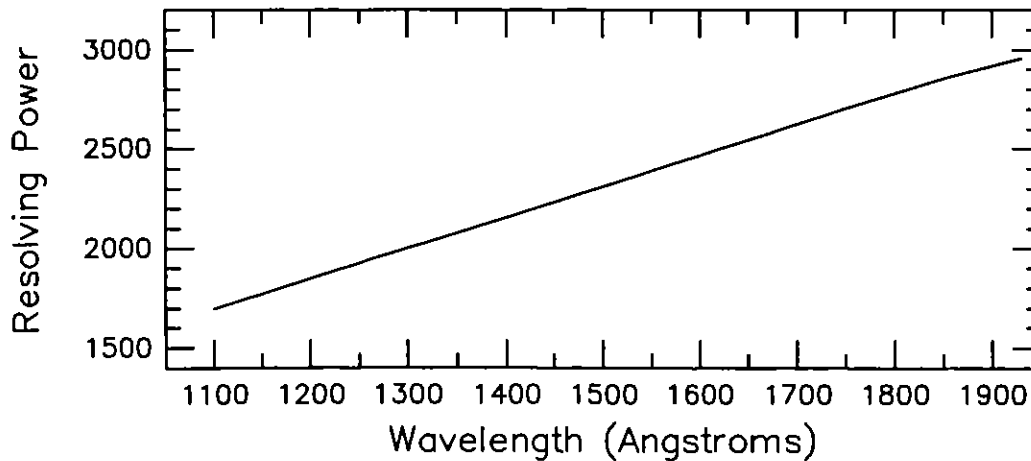

Figure 8-2. Resolving power for grating G140L.

8.1.3 Sensitivity Functions for the First-Order Gratings

Below are given sensitivities for the first-order gratings measured after the installation of the COSTAR mirrors, using the Large Science Aperture and in units of 10^{11} (counts sec^{-1} $diode^{-1}$) per incident (erg cm^{-2} sec^{-1} Å^{-1}). SSA sensitivity is about 50 to 70% of these values, with the larger value applying at longer wavelengths.

Table 8-2 Sensitivities for first-order gratings when used with the LSA.

Wavelength (Å)	Grating				
	G140L	G140M	G160M	G200M	G270M
1100	0.32	0.0014			
1150	21.4	0.74	0.69		
1200	84.5	2.34	3.13		
1250	150.	4.65	5.99		
1300	171.	7.12	7.90		
1350	164.	5.76	6.44		
1400	142.	5.12	5.48		
1450	112.	4.55	4.88		
1500	89.5	3.50	4.17		
1550	67.3	2.28	4.05		
1600	44.4	1.39	4.01	3.49	
1650	39.1	1.11	3.89	4.04	
1700	32.6	0.88	3.96	4.09	
1750	20.8		4.24	5.27	
1800	10.5		4.34	6.54	
1850	4.14		4.58	7.10	
1900	1.10		4.36	7.37	
1950			4.20	7.01	13.30
2000			4.07	7.53	15.35
2050			4.08	8.53	16.66
2100			4.11	9.18	17.13
2150				9.38	17.08
2200				9.23	17.52
2250				8.88	19.32
2300				8.75	21.55
2350				9.31	22.09
2400				10.70	24.28
2450				13.86	30.99
2500				19.08	39.65
2550					45.80

Table 8-2   (Continued)Sensitivities for first-order gratings when used with the LSA.

	Grating				
Wavelength (Å)	G140L	G140M	G160M	G200M	G270M
2600					48.78
2650					49.34
2700					48.33
2750					45.68
2800					42.04
2850					38.34
2900					34.69
2950					30.06
3000					24.15
3050					18.25
3100					13.77
3150					9.97
3200					6.44
3250					3.91
3300					2.63

8.2 Properties of the Echelle Gratings

8.2.1 Wavelength Coverage, Bandpass, and Sensitivity

The following tables summarize basic properties of the two echelle gratings. The dispersion in each order has not been listed but does not change if it is computed in velocity units. At the center of each order, the dispersion is 3.0 km s^{-1} per diode, at the long-wavelength end of each order it is 2.9 km s^{-1} per diode, and at the short-wavelength end of each order it is 3.1 km s^{-1} per diode.

Table 8-3   Properties of Grating Echelle-A

Order	Central Wavelength (Å)	Order Coverage (Å)	Bandpass per exposure (Å)	Scattered Light[a]	S_λ[b]
51	1102	1091 – 1113	5.90 – 5.55		0.037
50	1124	1113 – 1135	6.05 – 5.65		0.040
49	1147	1135 – 1159	6.15 – 5.75	0.061	0.78
48	1171	1159 – 1183	6.25 – 5.90	0.058	0.21
47	1196	1183 – 1209	6.40 – 6.00	0.055	0.38
46	1222	1209 – 1235	6.55 – 6.10	0.052	0.58
45	1249	1235 – 1263	6.70 – 6.25	0.049	0.82
44	1277	1263 – 1292	6.85 – 6.40	0.046	0.93
43	1307	1292 – 1322	7.05 – 6.55	0.044	0.96
42	1338	1322 – 1354	7.20 – 6.70	0.041	1.02
41	1371	1354 – 1387	7.40 – 6.85	0.039	1.04
40	1405	1387 – 1423	7.55 – 7.00	0.037	0.95
39	1441	1423 – 1460	7.80 – 7.20	0.035	0.79
38	1479	1460 – 1498	8.00 – 7.40	0.034	0.71
37	1519	1498 – 1539	8.25 – 7.55	0.032	0.73
36	1561	1539 – 1583	8.45 – 7.75	0.031	0.49
35	1606	1583 – 1629	8.70 – 7.95	0.030	0.36
34	1653	1629 – 1677	8.95 – 8.20	0.030	0.37
33	1703	1677 – 1729	9.25 – 8.40	0.029	0.33

a. "d" coefficient of Cardelli, Ebbets, and Savage (1993; see Section 9.2 on page 116). These apply only to the SSA.

b. Sensitivity function at blaze peak, in units of 10^{11} (counts diode^{-1} sec^{-1}) per incident (erg cm^{-2} sec^{-1} Å^{-1}). These values apply to the Large Science Aperture and are the sensitivities measured after the installation of the COSTAR mirrors.

Table 8-4   Properties of Grating Echelle-B

Order	Central Wavelength (Å)	Order Coverage (Å)	Bandpass per exposure (Å)	Scattered Light[a]	S_λ[b]
33	1703	1677 – 1729	9.3 – 8.4	0.045	0.47
32	1756	1729 – 1784	9.6 – 8.6	0.043	0.67
31	1813	1784 – 1842	9.9 – 8.9	0.041	0.92
30	1873	1842 – 1905	10.3 – 9.2	0.039	1.25
29	1938	1905 – 1971	10.7 – 9.5	0.037	1.71
28	2007	1971 – 2043	11.1 – 9.8	0.035	2.38
27	2082	2043 – 2120	11.5 – 10.1	0.033	3.52
26	2162	2120 – 2203	11.9 – 10.5	0.031	5.28
25	2248	2203 – 2293	12.4 – 10.9	0.030	7.64
24	2342	2293 – 2391	13.0 – 11.3	0.028	9.54
23	2444	2390 – 2497	13.6 – 11.7	0.026	11.17
22	2555	2497 – 2613	14.2 – 12.2	0.024	13.35
21	2676	2613 – 2740	14.9 – 12.7	0.022	14.43
20	2810	2740 – 2880	15.8 – 13.3	0.020	13.86
19	2958	2880 – 3036	16.7 – 13.9	0.018	10.92
18	3122	3036 – 3209	17.6 – 14.6	0.016	5.36

a. "d" coefficient of Cardelli, Ebbets, and Savage (1993; see Section 9.2 on page 116). These apply only to the SSA.

b. Sensitivity function at blaze peak, in units of 10^{11} (counts diode^{-1} sec^{-1}) per incident (erg cm^{-2} sec^{-1} Å^{-1}). These values apply to the Large Science Aperture and are the sensitivities measured after the installation of the COSTAR mirrors.

8.2.2 Echelle Wavelength Formats

The illustrations below provide a means of estimating where particular wavelengths fall within the echelle formats and where they lie relative to the blaze peak. Note that these layouts are purely schematic; the actual length of the free spectral range changes from order to order. The center of each order is at $m\lambda = 56200$.
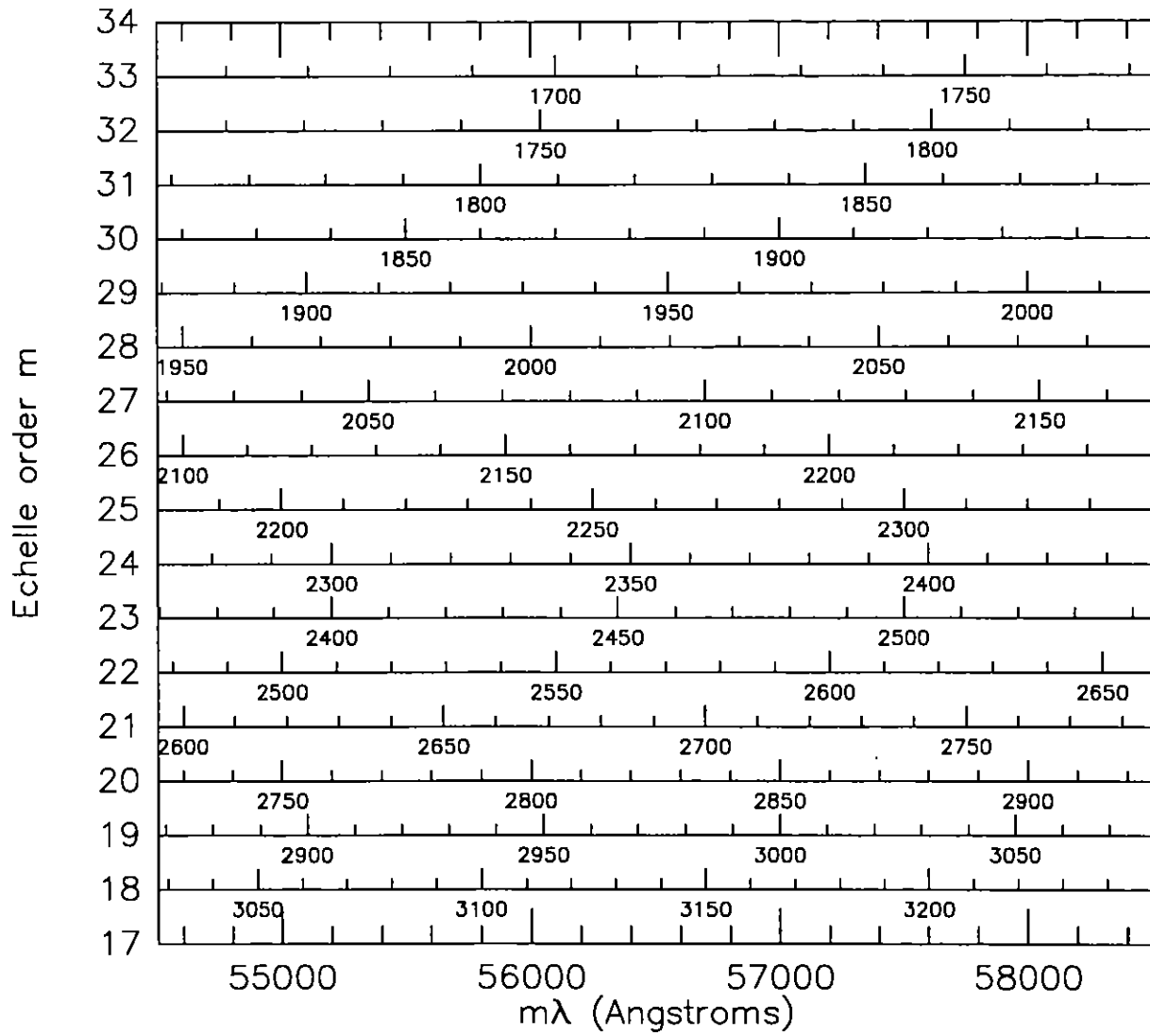
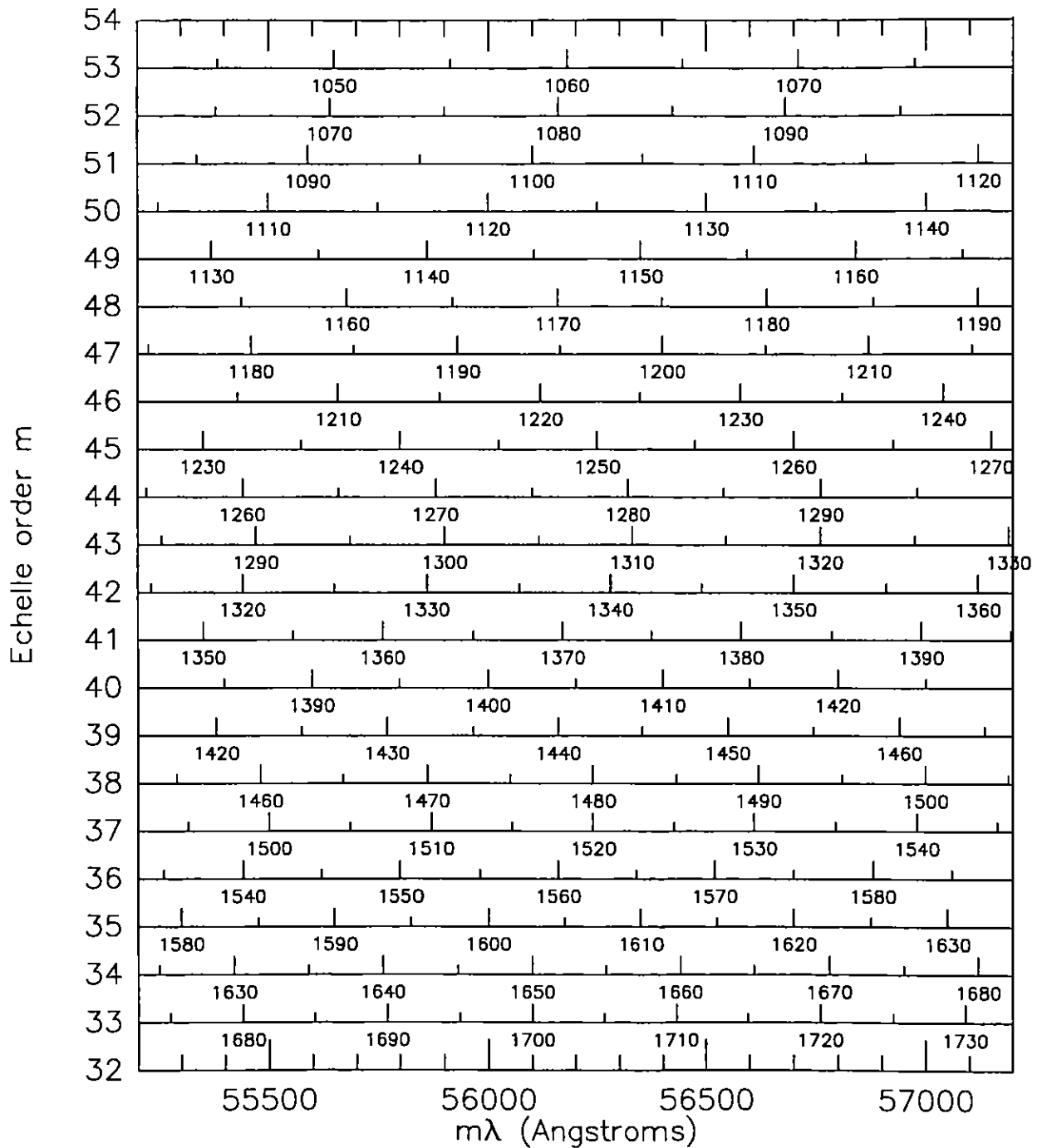**Figure 8-3.** Schematic format of wavelengths for Echelle-B.

Figure 8-4. Schematic format of wavelengths for Echelle-A.

8.2.3 Echelle Blaze Function

The figure below shows the echelle blaze function (also known as the "Ripple Function") in the form of sensitivity relative to the peak of the blaze as the product of wavelength and order number.
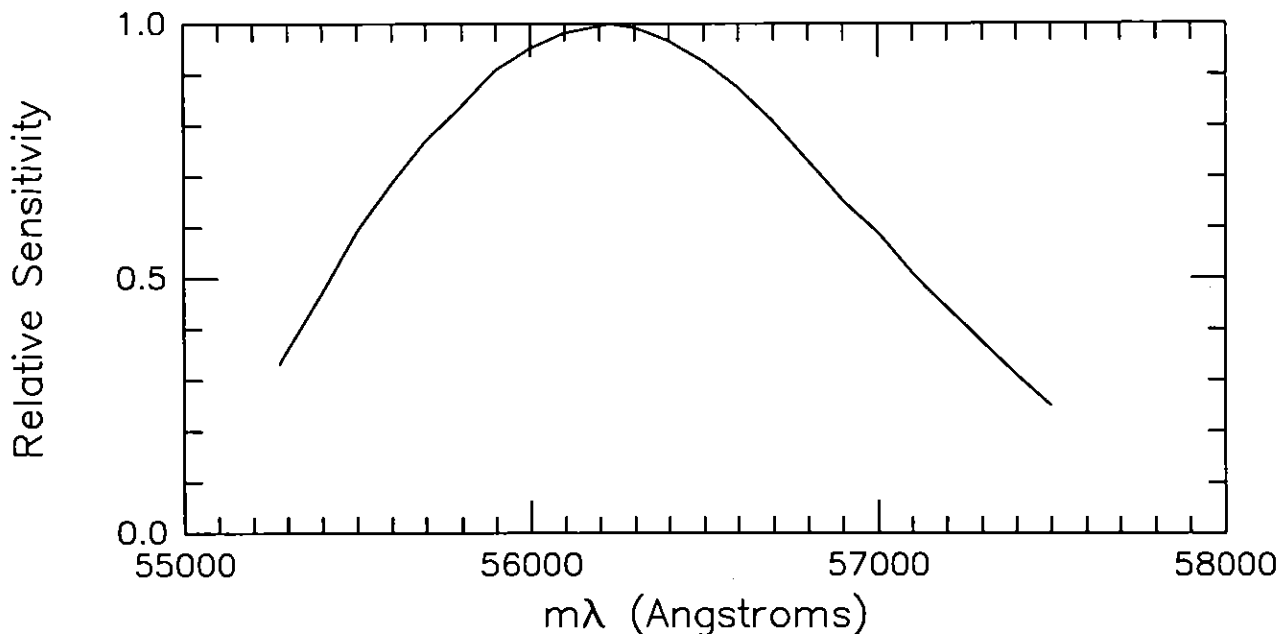

Figure 8-5. Normalized blaze function for the GHRS echelle gratings.

8.3 Standard Patterns for Substepping and Background Measurement

This table shows how each STEP-PATT pattern measures the background for a science exposure. Listed are the STEP-PATT number, the number of spectrum bins for which substepping occurs, the number of background bins measured, the diodes used to measure the background, the fraction of the total time spent measuring flux on the science diodes, the gratings for which the STEP-PATT is appropriate, and the shortest exposure that can be used for that pattern. The shortest exposure has been computed assuming COMB=4, FP-SPLIT=NO, and STEP-TIME=0.2. These minimum exposures can be reduced by half if COMB=2 is used and by a factor of four for COMB=NO. The complete expression for the minimum exposure time is:

$$t_{min} = FP\text{-}SPLIT \times STEP\text{-}TIME \times COMB \times [N_{background} + (N_{spectrum} \times ratio)],$$

where $N_{background}$ is the number of background bins (col. 3), $N_{spectrum}$ is the number of spectrum bins (col. 2), and *ratio* is from column 4. The minimum STEP-TIME is 0.2 sec. **You should specify your exposure time as an integral multiple of t_{min}.**

Table 8-5   STEP-PATT specifications

STEP-PATT number	Bins Measured		Spectrum/ Backgr Ratio	Diodes used for Background	On-target Efficiency	Appropriate Gratings	Minimum Exposure Time (sec)[a]
	Spectrum	Background					
1	1	0	1		1.00	all	0.8
2	2	0	1		1.00	all	1.6
3	4	0	1		1.00	all	3.2
4	2	2	8	science	0.89	first-order	14.4
5	4	2	8	science	0.94	first-order	27.2
6	2	2	8	science	0.89	echelle	14.4
7	4	2	8	science	0.94	echelle	27.2
8	2	2	8	corner	0.89	echelle	14.4
9	4	2	8	corner	0.94	echelle	27.2
10	2	2	1	science	0.50	first-order	3.2
11	4	2	1	science	0.67	first-order	4.8
12	2	2	1	science	0.50	echelle	3.2
13	4	2	1	science	0.67	echelle	4.8
14	2	2	1	corner	0.50	echelle	3.2
15	4	2	1	corner	0.67	echelle	4.8

a. Calculated using COMB=4, STEP-TIME=0.2, and FP-SPLIT=NO. Scale these values by 4, for example, if using FP-SPLIT=STD.

Table 8-6   Default STEP-PATT for science modes

Grating	Order	STEP-PATT
First-order	1	5
Ech-A	≥ 51	9
	< 51	7
Ech-B	≥ 31	9
	< 31	7

8.4 The Effects of Reddening in the Ultraviolet

Table 8-7

Average normalized ultraviolet extinction as a function of wavelength.

Wavelength (Å)	$A_\lambda/E(B\text{-}V)$	Wavelength (Å)	$A_\lambda/E(B\text{-}V)$
1100	11.70	2160	10.10
1200	10.20	2200	9.85
1300	9.19	2300	8.75
1400	8.54	2400	7.92
1500	8.29	2500	7.30
1600	8.03	2600	6.82
1700	7.85	2700	6.41
1800	7.90	2800	6.10
1900	8.38	2900	5.85
2000	9.05	3000	5.65
2100	9.90	3300	5.16

The table above lists extinction from interstellar reddening at ultraviolet wavelengths. These values have been derived to apply to our Galaxy, and the reddening laws for extragalactic objects can be very different. More information on the effects of reddening may be found in the bibliography in Chapter 9. The above values are from Code et al. (1976). Seaton (1979) has provided convenient fits to ultraviolet extinction for $x = 1/\lambda$, with λ in microns:

x range	$X(x) = A_\lambda/E(B-V)$
$2.70 \leq x \leq 3.65$	$1.56 + 1.048x + 1.01 / [\,(x - 4.60)^2 + 0.280]$
$3.65 \leq x \leq 7.14$	$2.29 + 0.848x + 1.01 / [\,(x - 4.60)^2 + 0.280]$
$7.14 \leq x \leq 10$	$16.17 - 3.20x + 0.2975x^2$

8.5 Instrumental Properties

8.5.1 The Point Spread Function (PSF)

The illustration below shows the PSF for the GHRS after the installation of the COS-TAR mirrors, to allow for estimation of the degree of scattered light in the vicinity of a bright object. Note that this PSF is only one-dimensional, and was only measured on one side of the center of the aperture at that; in fact the true PSF has two-dimensional structure. The relative throughput of the SSA at the wavelength at which this measurement was done (1450 Å) is 0.55.
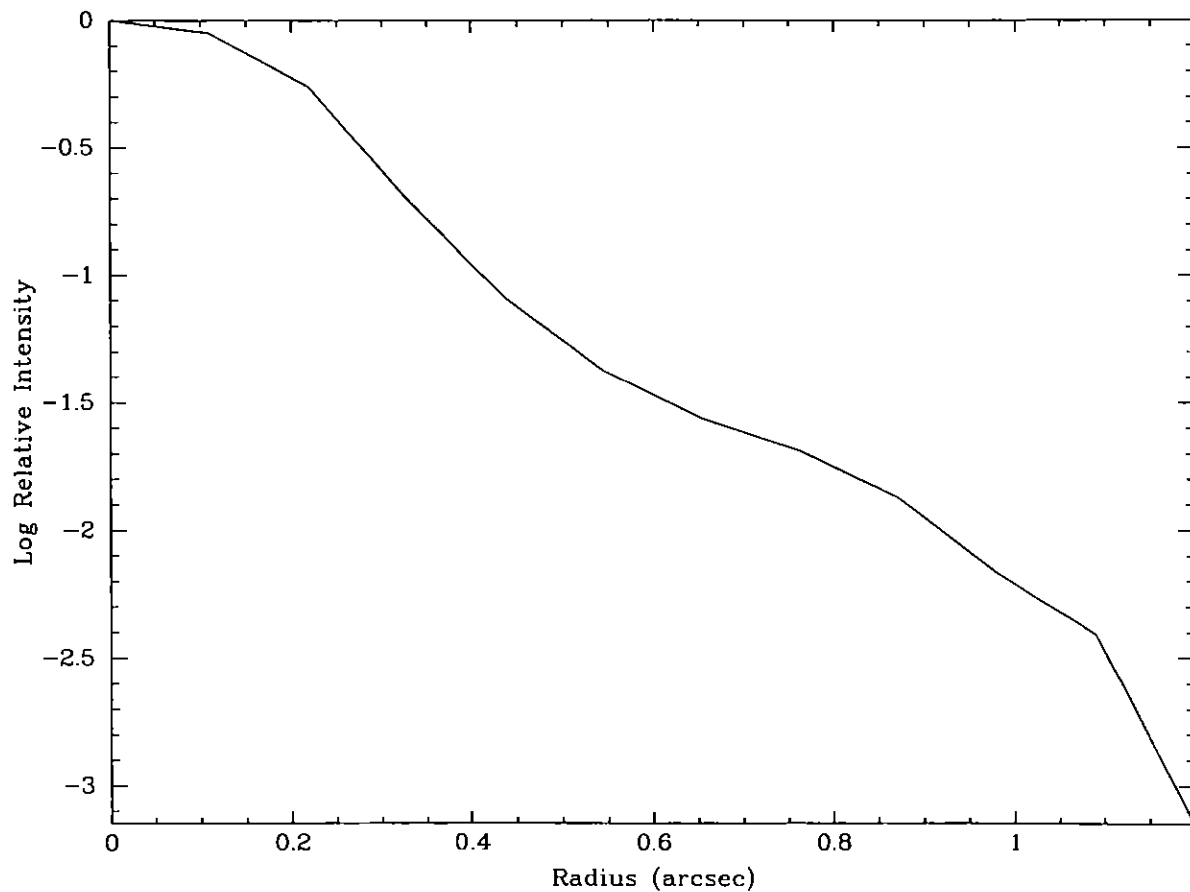
Figure 8-6. Normalized Point Spread Function for the GHRS Small Science Aperture. The curve is normalized to 1.0 at the origin.

8.5.2 The Differential Line Spread Function (LSF)

The Line Spread Function LSF is measured by observing the spectrum of a narrow-lined star with both the SSA and LSA and then determining what function must be convolved with the SSA observation to yield that seen in the LSA. These differential LSFs can be fitted well with Gaussians, and the Table below lists the FWHMs we found. The intrinsic LSF for the SSA is described by a Gaussian with a FWHM of 0.92 diodes (see Gilliland et al. 1992). Also listed in the Table are the expected FWHMs for the intrinsic LSF in the LSA determined by combining the FWHM of the SSA and the differential LSFs in quadrature.

Table 8-8   Differential Line Spread Functions

Grating	Wavelength (Å)	Differential LSF (diodes)	LSA FWHM (diodes)
G160M	1360	0.60	1.10
G160M	1900	0.72	1.17
G200M	1900	0.60	1.10
Ech-B	1900	0.82	1.23
Ech-B	2680	0.60	1.10
G140L	1200	1.05	1.40
G140L	1500	1.05	1.40

8.5.3 Detector Dark Count and the CENSOR Option

Each Digicon diode has its own discriminator, and if they are properly set the dark count rate measured is very low. On-orbit measurement has shown that both GHRS detectors have a dark rate less than the design goal of 0.01 counts diode^{-1} sec^{-1} at low geomagnetic latitudes and that the dominant noise source is cosmic rays. (For Side 2, the average dark away from the SAA is 0.012 ± 0.008 and for Side 1 it is 0.005 ± 0.002.) During SAA passage, the noise increases to a maximum of about 1 count diode^{-1} sec^{-1}. The scheduling software for *HST* uses known contours of the SAA and does not accumulate counts when the spacecraft is within those contours.

Even outside the SAA, observations show that "dark" counts tend to come in bursts. Approximately 15% of dark counts are produced by events that occur within a time of 8 μs or less. The CENSOR feature in Accumulation Mode allows you to ignore integrations with such high dark rates. CENSOR works by summing all 512 channels of the Digicon every 8 μs, and if that sum exceeds a threshold a coincident event is recorded. The flight software can reject and then repeat a single 8 μs time slice for which the coincidence sum exceeds a given level. Electronic noise in the analog summing circuit effectively limits the ability to discriminate events that produce less than about 8 simultaneous counts, so that only the high-amplitude tail of background events can be rejected. It is estimated that use of CENSOR can reduce the dark count rate by about 20%. Using CENSOR=YES is unlikely to degrade an observation (unless the object is

bright enough to cause a consistently high count rate), but the benefit is also low: only about a 10% gain in S/N in favorable cases.

The dark count rate is highly uniform over the diodes, so that a mean dark count rate is an excellent representation of what happens at the detector.

Summary:

- The pre-flight noise specification was 0.01 counts $diode^{-1}$ sec^{-1}. The average measured value is 0.005 for D1 and 0.008 for D2.
- The background is sensibly constant between -20 and $+20°$ geomagnetic latitude.
- At $±40°$ geomagnetic latitude, the extrema of *HST*'s orbit, the rate is twice that at the geomagnetic equator.
- The background rate is correlated with the cosmic ray and trapped particle flux. Calculations show that the dark noise can be accounted for by cosmic-ray-induced Cerenkov radiation in the faceplates of the Digicons.
- The background due to the direct penetration of cosmic rays into diodes is very low (0.0004 counts $diode^{-1}$ sec^{-1}).

When using CENSOR:

- Use the default STEP-TIME of 0.2 sec.
- Do not use CENSOR if the expected count rate exceeds about 100 counts per second per diode because real photon events will be rejected. In a severe case, all the data could be lost.
- Using CENSOR can drop the noise level by about 20%. The nominal Side 2 dark count rate is 0.012 counts per second per diode, so CENSOR=YES can lower it to 0.010.
- The following table shows the expected effects of using CENSOR. Rate is the target count rate per diode per second; the second column shows the standard S/N and the third column lists the S/N achieved with CENSOR=YES if the dark is 80% of its value without CENSOR. Signal-to-noise was calculated on a per diode basis for a

Table 8-9   Effects of CENSOR

Rate	Standard S/N	S/N with CENSOR=YES
100	999.94	989.91
10	316.05	312.91
1	99.45	98.56
0.1	30.02	30.01
0.01	6.90	7.22
0.005	3.95	4.21
0.001	0.91	1.00

nominal exposure time of 10,000 seconds (which is reduced to 9,800 if CENSOR is used because of the loss of 2% of the exposures).

Note that for rates exceeding one per second the effective loss of exposure time (due to 2% of the exposures being rejected) more than offsets any reduction of the noise. At a rate of 0.1 CENSOR has essentially no effect on S/N but for lower rates CENSOR can help.

8.5.4 Noise Rejection with FLYLIM

FLYLIM is a special commanding option for rejecting noise in cases where the source signal is at or below the noise level. The idea is that as *HST* circles the Earth it finds itself in different noise environments due to the changing magnetic field, and that influences the detected noise background. Also, the background noise occurs as discrete events from radiation in the space environment. If the source count level is well below the background noise, then spectra integrated over a sufficiently short interval that contain multiple counts are probably just noise, and should be rejected, whereas spectra with single counts are more likely to contain real information. The rejected spectra are discarded, which wastes observing time, but there is a net gain in signal-to-noise. A test-in-principle run in 1993 showed that the net background rate could be reduced to as low as 0.002 counts sec^{-1} $diode^{-1}$ for the Side 2 detector, which was a factor of four improvement over the mean dark rate. This gain was achieved at the cost of the loss of about 25% of the individual 0.2 second STEP-TIME integrations.

FLYLIM may now be used as an Optional Parameter with an ACCUM. If users believe that FLYLIM may be of help in their science program they should note the following:

* The use of the FLYLIM parameter should be arranged in advance, i.e., before the Phase I proposal deadline, through consultation with a GHRS Instrument Scientist.

* At the time this is written FLYLIM has not been fully tested and its use is at the observer's risk.

One alternative to FLYLIM is to use RAPID mode. The advantage of doing so is that all the observations are retained so that one may go back after the fact and try out algorithms for optimum signal extraction. If the FLYLIM parameter is set wrong due to imperfect knowledge of the source or because of variability, it would be possible to lose all the observations, but that would not happen with RAPID. The disadvantage of RAPID mode is that the spectrum is not fully sampled, so that the resolving power achieved is less.

If you decide you wish to use FLYLIM, we would suggest that you consider devoting one orbit of time as a first visit early in the cycle so that the true source count rate can be accurately and reliably determined.

For more information on using FLYLIM, we recommend that you read *"Calibration of GHRS Burst Noise Rejection Techniques,"* by Beaver et al.in *Calibrating Hubble Space Telescope*, edited by J.C. Blades and S.J. Osmer (1993, STScI), p. 304.

8.5.5 Count Rate Linearity

Deviations from linearity in the way in which the Digicons count photons at high rates were illustrated above in Figure 7-2. on page 85. The effective deadtime for the GHRS detectors has been measured to be 10.2 μs for detector D1. The same value has been assumed to hold for D2. Deviations from linearity are imperceptible below 10^3 and can be corrected to an accuracy of 1% up to a measured count rate of 20,000 (in units of counts diode^{-1} s^{-1}).

8.5.6 Image Stability

The images formed by the Digicons are vulnerable to the effects of the Earth's magnetic field. Over the course of a full orbit, the amplitude of the motion is about 50 microns per Gauss for D2 (about 15 microns peak-to-peak) and 10 microns per Gauss for D1. The 50 micron motion seen in D2 corresponds to the size of a diode. This geomagnetically-induced image motion ("GIMP"), together with thermal effects, is the underlying reason for breaking up long exposures into segments of no more than about 5 minutes each.

Chapter 9   *GHRS Bibliography*

We have tried to make this *Handbook* a comprehensive guide to using the Goddard High Resolution Spectrograph, but some of the best information on the instrument and the uses to which it can be put can be found in the open literature. Here we provide three lists. The first provides additional information on interstellar reddening in the ultraviolet. The next is technically oriented, and gives papers that provide detailed information on specific aspects of the GHRS. The final list is of scientific papers that have used GHRS data.

9.1 Ultraviolet Reddening and Extinction

"Ultraviolet Photometry from the Orbiting Astronomical Observatory. II. Interstellar Extinction."

Bless, R.C., and Savage, B.D. 1972, ApJ, 171, 293–308.

"Studies of Ultraviolet Interstellar Extinction with the Sky-survey Telescope of the TD-1 Satellite."

Nandy, K., Thompson, G.I., Jamar, C., Monfils, A., and Wilson, R. 1976, A&A, 51, 63–69.

"Empirical Effective Temperatures and Bolometric Corrections for Early-Type Stars."

Code, A.D., Davis, J., Bless, R.C., and Hanbury Brown, R. 1976, ApJ, 203, 417–434.

"Interstellar Extinction in the UV"

Seaton, M.J. 1979, MNRAS, 187, 73P–76P.

"Observed Properties of Interstellar Dust"

Savage, B.D., and Mathis, J.S. 1979, ARA&A, 17, 73–112.

9.2 GHRS-Related Technical Papers

"Ultraviolet High-Resolution Spectroscopy from the Space Telescope."

Ebbets, D.C., Brandt, J.C., and the HRS Investigation Definition Team 1983, PASP, 95, 543–549.

"Wavelengths and Intensities of a Platinum/Neon Hollow Cathode Lamp in the Region 1100–4000 Å"

Reader, J., Acquista, N., Sansonetti, C.J., and Sansonetti, J.E. 1990, ApJS, 72, 831–866.

"Status of the Goddard High Resolution Spectrograph in May 1991."

Ebbets, D.C., Brandt, J., Heap, S. 1991, in The First Year of *HST* Observations, edited by A.L. Kinney and J.C. Blades, p. 110-122,

"Scattered Light in the Echelle Modes of the Goddard High Resolution Spectrograph Aboard the Hubble Space Telescope. I. Analysis of Prelaunch Calibration Data."

Cardelli, J.A., Ebbets, D.C., and Savage, B.D. 1990, 365, 789–802.

"Scattered Light in the Echelle Modes of the Goddard High Resolution Spectrograph Aboard the Hubble Space Telescope. II. Analysis of Inflight Spectroscopic Observations."

Cardelli, J.A., Ebbets, D.C., and Savage, B.D. 1993, ApJ, 413, 401–415.

"Resolution and Noise Properties of the Goddard High Resolution Spectrograph"

Gilliland, R.L., Morris, S.L., Weymann, R.J., Ebbets, D.C., and Lindler, D.J. 1992, PASP, 104, 367–382.

This last paper is especially recommended for its discussion of the deconvolution of the effects of the Point Spread Function (PSF) and Line Spread Function (LSF) of *HST* and the GHRS.

"Final Report of the Science Verification Program for the Goddard High Resolution Spectrograph for the Hubble Space Telescope"

Ebbets, D.C. 1992, prepared for NASA/Goddard Space Flight Center by Ball Aerospace Systems Group.

This is a technical document prepared by Ball to fulfill a contractual requirement. It provides a detailed description of the tests and calibrations performed during the Science Verification phase that occurred immediately after the launch of *HST*. We cite it here for completeness, but a General Observer should usually be able to get the information that he or she needs from this *Handbook* or by consulting us.

"The Goddard High Resolution Spectrograph: Instrument, Goals, and Science Results"

Brandt, J.C., et al. 1994, PASP, 106, 890–908.

"Calibrating Hubble Space Telescope: Proceedings of a Workshop Held at STScI"

Blades, J.C., and Osmer, S.J., editors, published by STScI.

This contains several papers of relevance for data analysis.

"Calibration Product Review for the GHRS in Early Cycle 4"

Hulbert, S.J., Sherbert, L.E., Soderblom, D.R., and Leitherer, C.L., 1994, GHRS Instrument Science Report No. 67.

This Report summarizes the status of calibrations and calibration reference files for the GHRS. Each calibration file that is referred to in data headers is briefly described as well.

9.3 GHRS Scientific Papers

A number of GHRS-related papers are concentrated in three special volumes whose contents will not be itemized here:

- *The First Year of HST Observations,* 1991, edited by A.L. Kinney and J.C. Blades, and published by STScI.
- *Astrophysical Journal Letters,* volume 377, number 1, 1991.
- *Science with the Hubble Space Telescope,* 1992, edited by P. Benvenuti and E. Schreier, and published by ESO.
- *Astrophysical Journal Letters,* volume 435, number 1, 1994.

1992:

"The Abundance of Boron in Three Halo Stars"

Duncan, D.K., Lambert, D.L., and Lemke, M. 1992, ApJ, 401, 584–595.

"Ultraviolet Observations of the Gas Phase Abundances in the Diffuse Clouds Toward Zeta Ophiuchi at 3.5 Kilometers per Second Resolution"

Savage, B.D., Cardelli, J.A., and Sofia, U.J. 1992, ApJ, 401, 706–723.

"Fractionation of CO in the Diffuse Clouds Toward Zeta Ophiuchi"

Sheffer, Y., Federman, S.R., Lambert, D.L., and Cardelli, J.A. 1992, ApJ, 397, 482–491.

"Highly Ionized Atoms Toward HD 93521."

Spitzer, L., and Fitzpatrick, E.L. 1992, ApJ, 391, L41–L44.

"Ultraviolet and Optical Spectral Morphology of Melnick 42 and Radcliffe 136a in 30 Doradus"

Walborn, N.R., Ebbets, D.C., Parker, J.W., Nichols-Bohlin, J., and White, R.L. 1992, ApJ, 393, L13–L16.

"Detection of a Proton Beam During the Impulsive Phase of a Stellar Flare"

Woodgate, B.E., Robinson, R.D., Carpenter, K.G., Maran, S.P., and Shore, S.N. 1992, ApJ, 397, L95–L98.

1993:

"Interstellar Mg II and C IV Absorption Toward Mrk 205 by NGC 4319: An 'Optically-Thick' QSO Absorption System"

Bowen D.V., and Blades, J.C. ApJ, 403, L55–L58.

"Observations of 3C 273 with the Goddard High Resolution Spectrograph on the Hubble Space Telescope"

Brandt, J.C., et al. 1993, AJ, 105, 831–846.

"The Galactic Halo and Local Intergalactic Medium toward PKS 2155-304"

Bruweiler, F.C., Boggess, A., Norman, D.J., Grady, C.A., Urry, C.M., and Kondo, Y. 1993, ApJ, 409, 199-204.

"Ultraviolet Transitions of Low Condensation Temperature Heavy Elements and New Data for Interstellar Arsenic, Selenium, Tellurium, and Lead"

Cardelli, J.A., Federman, S.R., Lambert, D., and Theodosiou, C.E. 1993, ApJ, 416, L41-L44.

"Abundance of Interstellar Carbon Toward Zeta Ophiuchi"

Cardelli, J.A., Mathis, J.S., Ebbets, D.C., and Savage, B.D. 1993, ApJ, 403, L17-L20.

"Detection of Boron, Cobalt, and other Weak Interstellar Lines toward ζ Ophiuchi"

Federman, S.R., Sheffer, Lambert, D.L., and Gilliland, R.L. 1993, ApJ, 413, L51-L54.

"Quantitative Spectroscopy of K647 — the PNN of Ps1 in the Globular Cluster M15"

Heber, U., Dreizler, S., and Werner, K. 1993, Acta Astron., 43, 337-342.

"The Interstellar Abundances of Tin and Four Other Heavy Elements"

Hobbs, L.M., Welty, D.E., Morton, D.C., Spitzer, L., and York, D.G. 1993, ApJ, 411, 750-755.

"Time-Series Observations of O Stars. III. IUE and HST Spectroscopy of ζ Ophiuchi and Implications for the 'Photospheric Connection'"

Howarth, I.D. et al., 1993, ApJ, 417, 338-346.

"Hubble Space Telescope Spectra of the Phase-Modulated Wind in the SMC O+WR Binary R31"

Hutchings, J.B., Morris, S.C., and Bianchi, L. 1993, ApJ, 410, 803-807.

"Deceleration of Interstellar Hydrogen at the Heliospheric Interface"

Lallement, R., Bertaux, J.-L., and Clarke, J.T. 1993, Science, 260, 1095-1098.

Provides a good illustration of geocoronal Ly-α with the LSA and Echelle-A.

"High Resolution UV Stellar Spectroscopy with the HST/GHRS, Challenges and Opportunities for Atomic Physics"

Leckrone, D.S., Johansson, S., Wahlgren, G.M., and Adelman, S.J. 1993, Physica Scripta, T47, 149-156.

"Goddard High Resolution Spectrograph Observations of the Local Interstellar Medium and the Deuterium/Hydrogen Ratio Along the Line of Sight Toward Capella"

Linsky, J.L., Brown, A., Gayley, K., Diplas, A., Savage, B.D., Ayres, T.R., Landsman, W., Shore, S.N., and Heap, S.R. 1993, ApJ, 402, 694-709.

"The Boron Abundance of Procyon"

Lemke, M., Lambert, D.L., and Edvardsson, B. 1993, PASP, 105, 468-475.

"Detection of [O II] λ2471 from the Io Plasma Torus"

> McGrath, M.A., Feldman, P.D., Strobel, D.F., Moos, H.W., and Ballester, G.E. 1993, ApJ, 415, L55–L58.

"A Search for Proton Beams During Flares on AU Microscopii"

> Robinson, R.D., Carpenter, K.G., Woodgate, B.E., and Maran, S.P. 1993, ApJ, 414, 872–876.

"Observations of the Gaseous Galactic Halo Toward 3C273 with the Goddard High Resolution Spectrograph"

> Savage, B.D., Lu, L., Weymann, R.J., and Morris, S.L. 1993, ApJ, 404, 124–143.

"Goddard High Resolution Spectrograph Observations of Narrow Discrete Stellar Wind Absorption Features in the Ultraviolet Spectrum of the O7.5III Star ζ Persei"

> Shore, S.N., Altner, B., Bolton, C.T., Cardelli, J.A., and Ebbets, D.C. 1993, ApJ, 411, 864–868.

"The Early Ultraviolet Spectral Evolution of Nova Cygni 1992"

> Shore, S.N., Sonneborn, G., Starrfield, S., Gonzalez-Riestra, R., and Ake, T.B. 1993, AJ, 106, 2408–2428.

"High-Resolution Ultraviolet Observations of the Interstellar Diffuse Clouds toward μ Columbae"

> Sofia, U.J., Savage, B.D., and Cardelli, J.A. 1993, ApJ, 413, 251–267.

"Composition of Interstellar Clouds in the Disk and Halo. 1. HD 93521"

> Spitzer, L., and Fitzpatrick, E.L. 1993, ApJ,409, 299–318.

1994:

"Evidence for a Disk in the Wind of HD 93521: UV Line Profiles from an Axisymmetric Model"

> Bjorkman, J.E., Ignace, R., Tripp, T.M., and Cassenelli, J.P. 1994, ApJ, 435, 416–434.

"Interstellar and Intergalactic Magnesium and Sodium Absorption toward SN 1993J"

> Bowen, D.V., Roth, K.C., Blades, J.C., and Meyer, D.M. 1994, ApJ, 420, L71–L74.

"The Abundance of Heavy Elements in Interstellar Gas"

> Cardelli, J.A. 1994, Science, 265, 209–213.

"Interstellar Detection of the Intersystem Line Si II] l 2335 toward ζ Ophiuchi"

> Cardelli, J.A., Sofia, U.J., Savage, B.D., Keenan, F.P., and Dufton, P.L. 1994, ApJ, 420, L29–L32.

"GHRS Observations of Cool, Low-Gravity Stars. I. The Far-Ultraviolet Spectrum of α Orionis (M2Iab)"

Carpenter, K.G., Robinson, R.D., Wahlgren, G.M., Linsky, J.L., and Brown, A. 1994, ApJ, 428, 329–344.

"Hubble Space Telescope Goddard High Resolution Spectrograph H_2 Rotational Spectra of Jupiter's Aurora"

Clarke, J.T., Jaffel, L.B., Vidal-Madjar, A., Gladstone, G.R., Waite, J.H., Prange, R., Gerard, J.-C., Ajello, J., and James, G. 1994, ApJ, 430, L73–L76.

"Theoretical Modeling of GHRS Observations of the Of/WN-Type Star R136a5"

De Koter, A., Hubeny, I., Heap, S.R., and Lanz, T.W. 1994, ApJ, 435, L71–L74.

"Spectroscopy of Chromospheric Lines of Giants in the Globular Cluster NGC 6752"

Dupree, A.K., Hartmann, L., Smith, G.H., Rodgers, A.W., Roberts, W.H., and Zucker, D.B. 1994, ApJ, 421, 542–549.

"Boron in the Extreme Population II Star HD 140283 and the Production of the Light Elements in the Early Galaxy"

Edvardsson, B., Gustafsson, B., Johansson, S.G., Kiselman, D., Lambert, D.L., Nissen, P.E., and Gilmore, G. 1994, A&A, 290, 176–182.

"Intersystem Transitions of Interstellar Carbon Monoxide toward ζ Ophiuchi."

Federman, S.R., Cardelli, J.A., Sheffer, Y., Lambert, D.L., and Morton, D.C. 1994, ApJ, 432, L139-L142.

"Composition of Interstellar Clouds in the Disk and Halo. II. γ^2 Velorum"

Fitzpatrick, E.L., and Spitzer, L. 1994, ApJ, 427, 232–258.

"Search for CO Absorption Bands in IUE Far-Ultraviolet Spectra of Cool Stars"

Gessner, S.E., Carpenter, K.G., and Robinson, R.D. 1994, AJ, 107, 747–750.

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9.4 Acknowledgments

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Glossary of Terms and Abbreviations

Here we provide definitions and explanations of technical terms and abbreviations used in the text. The usual abbreviations found in HST-related documents (e.g., WFPC2, FGS) are not repeated here.

Blaze Function

The efficiency of an echelle grating drops sharply as one moves away from blaze center. The shape of the response function is virtually the same for the different orders and this function is known as the Ripple Function (see Section 8.2.3 on page 106).

Corner diodes

The detector area of the Digicons is laid out into specific diodes, each of which acts as an independent detector. There are 500 science diodes, each of which is skinny but tall, four focus diodes (see below), and four corner diodes. The corner diodes are large rectangles (0.1 × 1 mm) of detector area above and below the science diodes and are used for measuring background.

Cycles

Proposals to use HST are solicited and reviewed on roughly an annual basis. However, because HST's properties changed fundamentally when COSTAR and WFPC2 were installed, Cycle 3 was defined to end at the time of the Servicing Mission. Cycle 4 began at the end of SMOV. Cycle 6 will end at the time of the 1997 Servicing Mission.

CVZ

Continuous Viewing Zones. The inclined orbit of HST allows for uninterrupted observations of objects in some declination ranges at certain times. See the *Call for Proposals* for further information.

DEFCAL

Short for Deflection Calibration. All GHRS acquisitions begin with a DEFCAL, which measures the instantaneous location of the images on the onboard spectrum lamps and then compares that location to the nominal coordinates stored in the onboard database. The differences can range over several deflection steps in response to thermal and magnetic drifts. The offsets are applied to the database coordinates of the science apertures to provide an updated estimate of their location.

Focus diodes

See Chapter 7 to see how the diodes in the GHRS Digicons are configured. At both ends of the array of 500 science diodes are two focus diodes. The focus diodes are smaller than the science diodes and are square. The image of the LSA is deflected to the focus diodes to generate MAPs and IMAGEs. The focus diodes are 25 microns square.

GIMP

Geomagnetically-induced image motion problem. This problem underlies our recommendation to have no single exposure be longer than about 5 minutes in length.

GSC

Guide Star Catalog, the list used to find stars upon which the Fine Guidance Sensors can lock to control the pointing of HST.

LSA

Large Science Aperture. This is a square opening at the front of the GHRS that is used to acquire stars and for some science observations. Its dimensions were 2.00 arcsec square before COSTAR is installed and 1.74 arcsec square afterwards. The name used for the LSA will continue to be "2 . 0".

OPUS

The "OSS and PODPS Unified System." The Observation Support System was the facility located at STScI for real-time interaction between the ground and the *HST* spacecraft, and PODPS was the pipeline data reduction system. They have now been combined into ne operation called OPUS.

Phase I

A Phase I proposal for *HST* includes just the information need by the Telescope Allocation Committee (TAC) and STScI to judge scientific merit and technical feasibility. In

addition to the scientific justification, you are asked to provide a list of the targets that you wish to observe and a brief description of the observations themselves. We recommend adding comments to provide a clearer explanation of what you intend, even if they are not required.

Phase II

The Phase II proposal is written once the Phase I proposal has been accepted for the HST science program. The Phase II proposal includes all the detailed specifications that are needed to turn your science program into the commands that the spacecraft will execute. As with Phase I, we recommend the liberal use of comments to help ensure that your goals will be achieved.

Ripple Function

See Blaze Function

RPS2

RPSS was the Remote Proposal Submission System. RPS2 is a second-generation version of RPSS that allows the user to plan their observations in detail so as to make efficient use of on-orbit time. To learn more about RPS2, consult the Presto Web page:

http://stsci.edu/observer.html

SAA

South Atlantic Anomaly. A region lying over southeastern South America where the earth's radiation belts dip low, leading to high particle background rates for satellites in Low Earth Orbit. GHRS observations are suspended during passage through the SAA.

Science diodes

These are the primary diodes used for data acquisition. There are 500 of them, and they are 25 microns wide by 400 microns tall.

Side 1, Side 2

GHRS is split into two "sides," one for the short-wavelength detector (D1) and one for the long-wavelength detector (D2). The sides operate independently but depend on each other for communication with the spacecraft. The installation of the GHRS Repair Kit during the HST Servicing Mission has meant that all GHRS communications are now through Side 2. Moreover, Side 2 now solely controls the grating carrousel and LSA shutter.

SPYBAL

SPectrum Y BALance. A SPYBAL consists of a quick observation of the spectrum calibration lamp SC2 at a standard wavelength setting to ensure that the spectrum is properly centered on the diodes in the cross-dispersion direction. The y position at this

standard wavelength is compared to a stored value and the difference is applied to the observations made with the proposal configuration until another SPYBAL is done. A SPYBAL is normally done before each new use of a different spectrum element, such as a grating. The resultant spectrum is provided to the observer and can be used to improve the default wavelength calibration.

SSA

Small Science Aperture. The nominal (pre-COSTAR) size was 0.25 arcsec square, but after COSTAR it is 0.22 arcsec square. The name for this aperture will continue to be "0.25".

STEIS

Space Telescope Electronic Information Service. This service provides on-line news, information, and documents via anonymous ftp. To use it, *ftp* to *stsci.edu* (Internet node 130.167.1.2) and login with username *anonymous*, using your last name as password. Use *get* to transfer the README file in the entry directory; this will provide a general explanation of how to access STEIS information. STEIS is now obsolete and the World Wide Web should be used instead. The URL for GHRS information is:

http://www.stsci.edu/ftp/instrument_news/GHRS/topghrs.html

STEP-PATT

STEP-PATT is the pattern of operations undertaken in an ACCUM. A typical STEP-PATT defines the relative proportions of time spent accumulating on the science diodes versus time with the background diodes. See Section 8.3 on page 106.

STEP-TIME

STEP-TIME is the exposure time for the smallest unit of an exposure. For example, during an acquisition, STEP-TIME is the amount of time spent at each dwell point while executing a spiral search pattern. During an ACCUM, the detector integrates for a STEP-TIME before reading the diodes and adding their contents to the memory. A unit of STEP-TIME is spent executing each portion of a STEP-PATT, for example.

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