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Hubble Space Telescope Primer for Cycle 18

An Introduction to *HST* for Phase I Proposers

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Operated by the Association of Universities for Research in Astronomy, Inc., for the National Aeronautics and Space Administration

How to Get Started

If you are interested in submitting an *HST* proposal, then proceed as follows:

- Visit the Cycle 18 Announcement Web page:

http://www.stsci.edu/hst/proposing/docs/cycle18announce

Then continue by following the procedure outlined in the Phase I Roadmap available at:

http://apst.stsci.edu/apt/external/help/roadmap1.html

More technical documentation, such as that provided in the Instrument Handbooks, can be accessed from:

http://www.stsci.edu/hst/HST_overview/documents

Where to Get Help

- Visit STScI's Web site at: http://www.stsci.edu
- Contact the STScI Help Desk. Either send e-mail to help@stsci.edu or call 1-800-544-8125; from outside the United States and Canada, call [1] 410-338-1082.

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CHAPTER 1:

Introduction

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1.1 About this Document

This Primer provides an introductory overview of the Hubble Space Telescope (*HST*) and contains basic information on the telescope's operations and the capabilities of its instruments. While the Primer is of interest to anyone who wants to learn about *HST*, it is intended to be a companion document to the *HST Call for Proposals* (see Section 1.3). The *HST Call for Proposals* discusses the policies and procedures for submitting a Phase I proposal for *HST* observing or archival research. Technical aspects of proposal preparation are presented in the Primer, and a thorough understanding of the material presented here is essential for the preparation of a competitive proposal. Also, the Primer explains how to calculate the appropriate number of orbits for your Phase I observing time requests.

The Primer is only available electronically in HTML and PDF formats. The HTML version is optimized for on-line browsing and contains many links to related or more detailed information, both within the document itself and to other STScI documents. For those who prefer to read a hardcopy, the PDF version was optimized for printing.

The PDF version also provides a search capability for quick access to specific information.

In a hardcopy printout of the PDF version, any links to information on the Internet will appear as underlined text. You may look up the Internet address of the corresponding link in Appendix D.

1.2 What's New This Cycle

Servicing Mission 4 (SM4; see Section 1.2 of the *HST* Call for Proposals) started with the Atlantis launch on May 11, 2009 and was completed, upon return of the Shuttle, on May 24, 2009. Space Shuttle astronauts installed two new instruments, the Wide Field Camera 3 (WFC3) and the Cosmic Origins Spectrograph (COS), together with a new set of gyros and other flight hardware. WFC3 has replaced the Wide Field Planetary Camera 2 (WFPC2) as the on-axis instrument; COS has replaced COSTAR. The Space Telescope Imaging Spectrograph (STIS) that had suffered a serious electronics failure in August 2004, was fixed successfully. The ACS-Repair successfully recovered the ACS/WFC that had ceased to be operational with the ACS/HRC in January 2007 for a failure of the electronics. The Advanced Camera for Surveys Wide-Field Camera (ACS/WFC) and the Solar Blind Channel (ACS/SBC) are now operating nominally. The High Resolution Channel (ACS/HRC) is not operational any longer, as it could not be recovered during SM4. The Near Infrared Camera and Multi-Object Spectrometer (NICMOS) will be available in Cycle 18. Please consult the Cycle 18 Announcement Web page for up to date information on the status of *HST* instrumentation.

1.3 Resources, Documentation and Tools

1.3.1 Phase I "Roadmap"

The Phase I Proposal Roadmap is a high level step-by-step guide to writing a Phase I Proposal. Links to the appropriate section of the various documents (Call for Proposals, Primer, etc.) are given for each step.

1.3.2 Cycle 18 Announcement Web Page

The Cycle 18 Announcement Web page contains links to information and documentation (including this Primer) that will be of use to you in the preparation of an *HST* proposal. It also contains any late-breaking updates on the Phase I process and answers to frequently asked questions.

1.3.3 Cycle 18 Call for Proposals

The Call for Proposals discusses the policies and procedures for submitting a Phase I proposal for *HST* observing or Archival Research. It also provides a summary of the proposal process from proposal submission to execution of the observations. The Call for Proposals is accessible from the Cycle 18 Announcement Web page.

1.3.4 Instrument Handbooks

The Instrument Handbooks are the primary source of information for the *HST* instruments. You should consult them for any information that goes beyond what is presented in this Primer. Please use current versions when preparing your Phase I proposal. They are available for all instruments, including former instruments that may be of interest for archival research. The handbooks are distributed electronically and may be accessed from the *HST* Documents Web page. This page also provides links to more detailed technical information such as that provided in Instrument Science Reports.

1.3.5 The Astronomer's Proposal Tool (APT) and the Aladin Sky Atlas

The Astronomers Proposal Tool (APT) was introduced in Cycle 12 as the interface for all Phase I and Phase II proposal submissions for *HST*. The current version of APT, along with minor bug fixes and enhancements, is essentially the same system as was used last cycle. See the Whats New button in APT for details on the changes. The APT Web Page contains information on the installation and use of APT.

The Aladin Sky Atlas is available via the APT. This interface can be used to display *HST* apertures on images of the sky. This tool brings a variety of benefits to users including access to a wide variety of images and catalogs; note that the GALEX catalog is now available to assist in checking for potentially dangerous objects for the UV detectors. Training documentation and videos can be found on the APT Training Materials page.

One change to APT/Aladin is that Starview is no longer supported, and has been replaced with an Aladin link to the Hubble Legacy Archive footprint service.

1.3.6 Exposure Time Calculators (ETCs)

This Primer, together with the instrument handbooks, provides a means of estimating acquisition times, exposure times, and other observational parameters. Proposers should realize that such tables and illustrations are only approximations, and that reliable calculations are best done with the software tools STScI provides: the Exposure Time Calculators (ETCs) and APT (Section 1.3.5). Those software tools fully embody knowledge of the complex operations of the instruments that can be confusing to describe in a handbook.

STScI provides ETCs for each of the *HST* instruments. Please use these Web-based electronic tools to estimate exposure times needed to achieve the signal-to-noise ratio required for your project. The ETCs provide warnings about target count rates that exceed linearity and safety limits. They can be accessed from the individual instrument Web pages which, in turn, are accessible from the *HST* Instruments Web page. Alternatively, they can be accessed from the Phase I Proposal Roadmap.

1.3.7 *HST* Data Archive

The *HST* Data Archive forms a part of the Multimission Archive at STScI (MAST). The *HST* Data Archive contains all the data taken by *HST*. Completed observations from both GO and GTO programs are available to the community upon the expiration of their proprietary periods. Observations taken under the Treasury program (see Section 3.2.6 of the Call for Proposals) and GO Pure Parallel program (see Section 4.2.2 of the Call for Proposals) types carry no proprietary period.

The MAST Web page provides an overview of the *HST* Data Archive as well as the procedures for retrieving archival data. Section 7.2 contains additional information about the *HST* Data Archive. A copy of the Archive is maintained at the Space Telescope - European Coordinating Facility (ST-ECF) in Garching to which European requests should normally be addressed. The Canadian Astronomy Data Centre also maintains a copy of public *HST* science data only, and is the preferred source for Canadian astronomers.

The Hubble Legacy Archive (HLA) is a recent project to offer enhanced *HST* archive products. The HLA is a joint project of the Space Telescope Science Institute, the European Coordinating Facility, and the Canadian Astronomy Data Centre. It offers access to high level *HST* products including composite images and interactive tools for previewing data products. Section 7.3 contains more detailed information about the HLA.

An *HST* Duplication Checking Web tool is also available at MAST. Instructions for its use, and information about other tools for duplication checking are given in Section 5.2.2 of the Call for Proposals.

1.3.8 Data Reduction and Calibration

The *HST Data Handbook* describes the data produced by the instruments. Data Handbooks for each of the instruments will be made available to observers from the Documents Web page. The STIS, WFPC2 and ACS Data Handbooks have been updated recently. COS and WFC3 Data Handbooks were released in March 2009 and in January 2009 respectively and are available through the Documents Web page.

The Space Telescope Science Data Analysis Software (STSDAS) Web page has links to the software used to calibrate and analyze *HST* data, and to documentation on its use. See Section 7.1 for details.

The *HST Dither Handbook* provides general information on dither patterns, drizzling, and various considerations that should be taken into account when designing dithered observations. More detailed information specific to each instrument should be obtained from the Instrument Handbook and Data Handbook relevant to a given instrument.

1.4 STScI Help Desk

If this *HST* Primer and the materials referenced above do not answer your questions, or if you have trouble accessing or printing Web documents, then contact the Help Desk. You may do this in either of two ways:

- Send email to help@stsci.edu
- Call 1-800-544-8125 or, from outside the United States and Canada, [1] 410-338-1082.

CHAPTER 2:

System Overview

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2.1 Telescope Design and Field-of-View

The design and layout of *HST* are shown schematically in Figure 2.1. The telescope receives electrical power from two solar arrays, which are turned (and the spacecraft rolled about its optical axis) so that the panels face the incident sunlight. Nickel-hydrogen batteries power the telescope during orbital night. Two high-gain antennae provide communications with the ground via the Tracking and Data Relay Satellite System (TDRSS). Power, control, and communications functions are carried out by the Support Systems Module (SSM) that encircles the primary mirror.

The science instruments (SIs) are mounted in bays behind the primary mirror. The WFC3 occupies one of the radial bays with an attached 45-degree pickoff mirror that allows it to receive the on-axis beam. There are three Fine Guidance Sensors (FGSs) which occupy the other radial bays and receive light 10–14 arcminutes off-axis. Since at most two FGSs are required to guide the telescope, it is possible to conduct astrometric observations with the third FGS. The remaining SIs are mounted in the axial bays and receive images several arcminutes off-axis.

When referring to the *HST* and its focal plane, we use a coordinate system that is fixed to the telescope and consists of three orthogonal axes: U1, U2 and U3. As shown in Figure 2.1, U1 lies along the optical axis, U2 is parallel to the solar-array rotation axis, and U3 is perpendicular to the solar-array axis. (Note: Some *HST* documentation uses the alternative V1, V2, V3 coordinate system for which V1=U1, V2= –U2 and V3= –U3.)

Figure 2.1: The Hubble Space Telescope. Major components are labelled, and definitions of the U1,U2,U3 spacecraft axes are indicated.

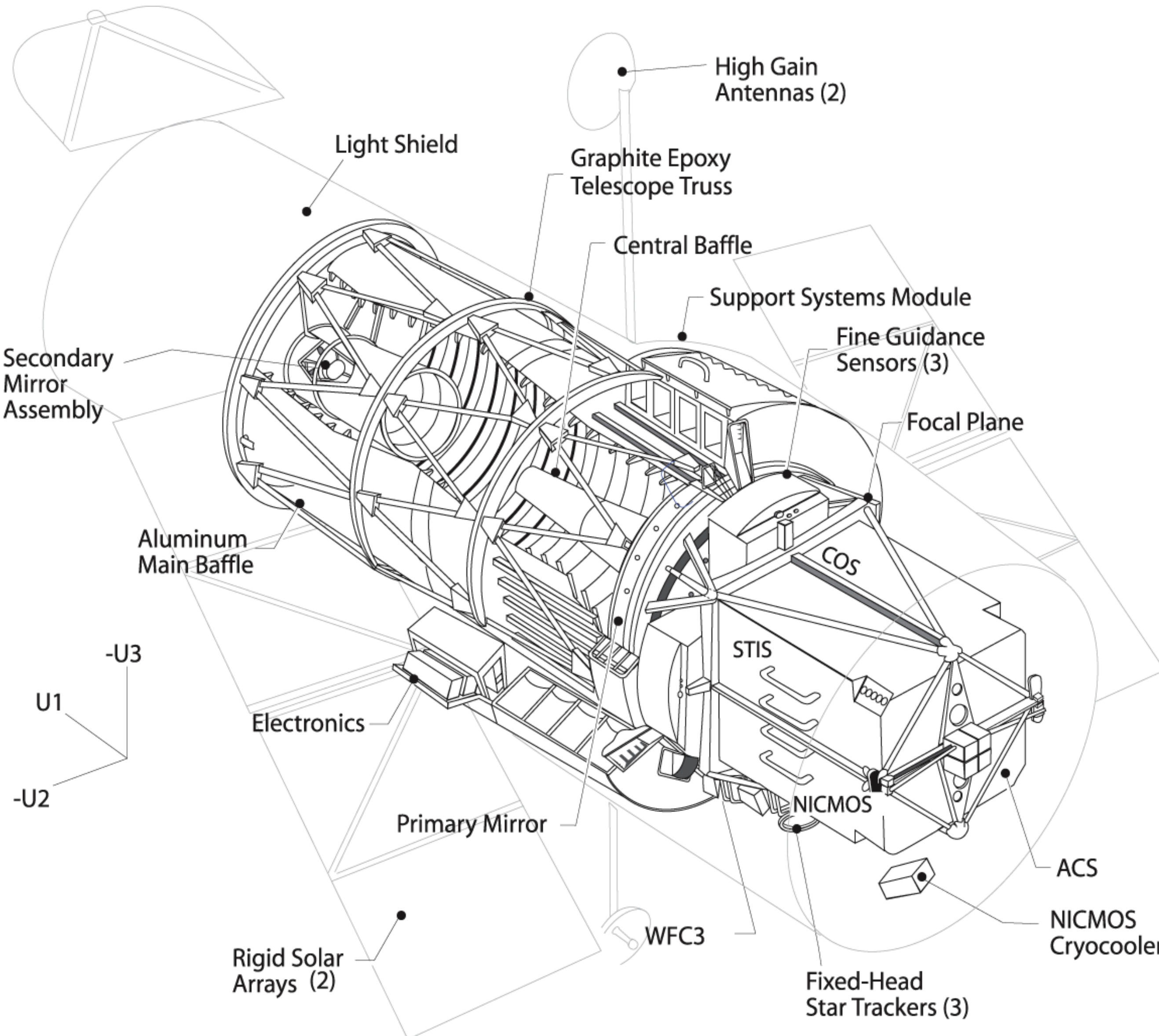

Figure 2.2: The *HST* field-of-view with the locations of the SI and the FGS apertures in the (U2,U3) focal plane. It shows the layout of the instrument entrance apertures in the telescope focal plane as projected onto the sky. The scale in arcsec is indicated.

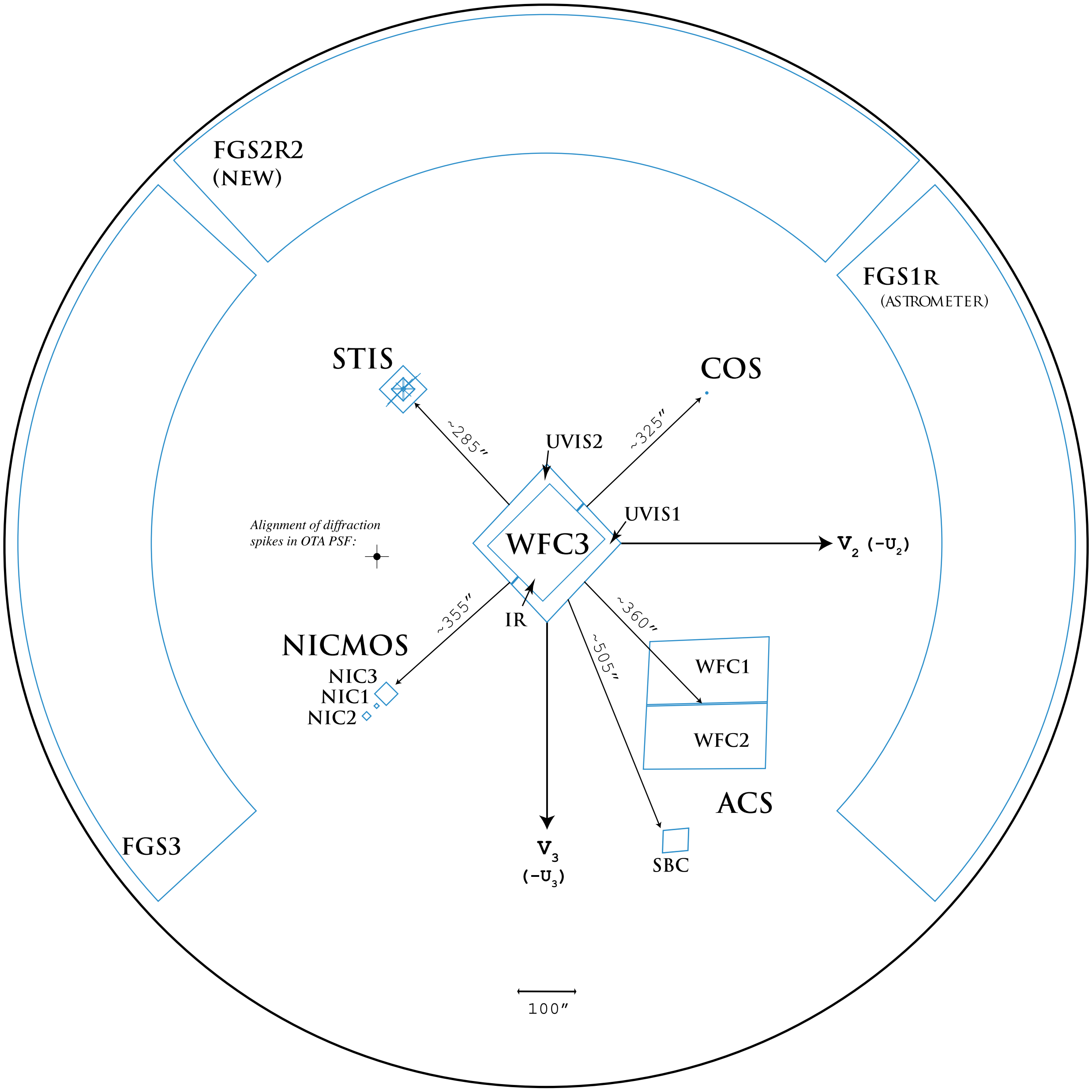

Table 2.1 lists the rough effective locations of the SI apertures in the U2,U3 coordinate system. Precise values depend on subtleties in aperture definitions and operational modes. The HST Instrument Handbooks (see Section 1.3) should be consulted for more accurate instrument aperture locations and detailed characteristics.

Table 2.1: Nominal Effective Relative Aperture Locations

Instrument	Aperture	U2 (arcsec)	U3 (arcsec)
ACS	WFC	–259	–239
	SBC	–205	–467
COS		+229	-229
FGS	FGS1R	–722	8
NICMOS	NIC1	294	–288
	NIC2	321	–314
	NIC3[1]	269	–256
STIS		214	225
WFC3	UVIS	2	-4
	IR	1	-1

1. Position shown is for NIC1 and NIC2 compromise PAM location.

2.2 Orbital Constraints

HST is in a relatively low orbit, which imposes a number of constraints upon its observations. As seen from *HST*, most targets are occulted by the Earth for varying lengths of time during each 96-minute orbit. Targets lying in the orbital plane are occulted for the longest interval—about 44 minutes per orbit. These orbital occultations, analogous to the diurnal cycle for ground-based observing, impose the most serious constraint on *HST* observations. (Note that in practice the amount of available exposure time in an orbit is further limited by Earth-limb avoidance limits, the time required for guide star acquisitions or re-acquisitions, and instrument overheads.)

2.2.1 Continuous Viewing Zone (CVZ)

The length of target occultation decreases with increasing angle from the spacecraft orbital plane. Targets lying within 24 degrees of the orbital poles are not geometrically occulted at any time during the *HST* orbit. This gives rise to so-called Continuous Viewing Zones (CVZs). The actual size of these zones is less than 24 degrees due to the fact that *HST* cannot observe close to the Earth limb (see Section 2.3).

Since the orbital poles lie 28.5 degrees from the celestial poles, any target located in two declination bands near +/– 61.5 degrees may be in the CVZ at some time during the 56-day *HST* orbital precession cycle. Some regions in these declination bands can be unusable during the part of the year when the sun is too close to the region. The number and duration of CVZ passages depend on the telescope orbit and target position, and may differ significantly from previous cycles. Please refer to the HST

Orbital Viewing and Schedulability Web Page for information on determining the number and duration of CVZ opportunities in Cycle 18 for a given target location. Also note that the South Atlantic Anomaly (SAA; see Section 2.2.2) limits any *uninterrupted* observation to no more than 5-6 orbits.

The brightness of scattered earthshine background during CVZ observations is not greater than during non-CVZ observations since the same bright-earth limb avoidance angle is used. However, the duration of relatively high background can be much longer for CVZ observations than for non-CVZ observations, because the line of sight may continuously graze the bright earth-limb avoidance zone during CVZ observations.

In general, CVZ should not be requested if observations are sky-background limited under normal observing conditions. The increased earthshine means that the CVZ offers virtually no efficiency gain for programs doing background-limited broadband imaging in the optical or infrared. There have been cases in the past (e.g. the Hubble Deep Field observations) where optical imaging has been interleaved with other kinds of observations. However such observations are difficult to schedule and require strong science justification. Observers contemplating using CVZ in this way are encouraged to contact the STScI Help Desk (see Section 1.4) prior to proposing. CVZ observations are also generally incompatible with special timing requirements (e.g., timing links, special spacecraft orientations, or targets of opportunity; see Section 4.1.1 of the Call for Proposals for more details).

2.2.2 South Atlantic Anomaly (SAA)

The South Atlantic Anomaly, a lower extension of the Van Allen radiation belts, lies above South America and the South Atlantic Ocean. No astronomical or calibration observations are possible during passage of the spacecraft through the SAA because of the high background induced in the science instruments and FGSs, with the exception of certain infrequent and specialized WFC3/IR observations. As the *HST* orbit precesses and the earth rotates during the day, the southern part of the *HST* orbit intersects the SAA for 7 to 9 orbits in a row (so-called “SAA-impacted” orbits). These SAA-impacted orbits are followed by 5 to 6 orbits (8 to 10 hours) without SAA intersections. During intersections, *HST* observing activities must be halted for approximately 20 to 25 minutes. This effectively limits the longest possible uninterrupted observations, *even in the CVZ*, to 5 orbits. Note that the STIS MAMAs and the ACS SBC cannot be used during any part of an orbit that is even partially impacted by the SAA. This means that these detectors can only be used during the 5 to 6 orbits each day that are completely free of SAA intersections. This restriction does not apply to COS.

2.2.3 Predicted *HST* Position

Because *HST's* orbit is low, atmospheric drag is significant. Moreover, the amount of drag varies depending on the orientation of the telescope and the density of the atmosphere which, in turn, depends on the level of solar activity. Consequently, it is difficult to predict in advance where *HST* will be in its orbit at a given time. For example, the predicted position of the telescope made two days in advance can be off by as much as 30 km from its actual position. An estimated position 44 days in the future may be off by ~ 4000 km (95% confidence level).

This positional uncertainty can affect observations of time-critical phenomena and also those of near-earth solar system bodies. In the former case the target could be behind the Earth at the time of the event, and it may not be known if a given event will be observable until a few days before the observation. In the latter case the positional uncertainty could introduce uncertainties in the parallax correction.

2.3 Pointing Constraints

HST uses electrically driven reaction wheels to perform all slewing required for guide star acquisition and pointing control. A separate set of rate gyroscopes provides attitude information to the pointing control system (PCS). The slew rate of *HST* is limited to approximately 6 degrees per minute of time. Consequently, about one hour is needed to go full circle in pitch, yaw or roll. After the telescope arrives at the new target, attitude updates and guide star acquisitions take an additional 13 minutes**.** As a result, large maneuvers are costly in time and are generally scheduled for periods of Earth occultation or crossing of the South Atlantic Anomaly (see Section 2.2.2). The target-to-sun angle at the time of observation must be >50 degrees.

Exceptions have been made to these rules under three-gyro operations in the past. For example, observations have been made of Venus and a comet despite the sun angle being slightly less than 50 degrees. Significant work is required to support such observations, so very compelling scientific justification is necessary for approval. See Section 4.1.4 of the Call for Proposals for restrictions on observations of Solar System targets, along with Section 5.3 of the Primer.

2.4 Orientation and Roll Constraints

The orientation (ORIENT) of the telescope is defined as the position angle of the U3 axis on the sky measured from North through East (see Figure 2.2).

In principle, *HST* is free to roll about the U1 optical axis. However, this freedom is limited by the need to keep sunlight shining on the solar arrays and by a thermal design that assumes that the Sun always heats the same side of the telescope.

For a particular pointing, the orientation of the telescope that optimizes the solar-array positioning with respect to the Sun is called the **nominal roll**. At this orientation the Sun is in the half-plane defined by the U1 axis and the negative U3 axis (see Figure 2.1). Consequently, the nominal roll required for a particular observation depends on the location of the target and the date of the observation. Observations of the same target made at different times will, in general, be made at different orientations. Some departures from nominal roll are permitted during *HST* observing (e.g., if a specific orientation is required on a particular date or if the same orientation is required for observations made at different times).

Off-nominal roll is defined as the angle about the U1 axis between a given orientation and the nominal roll. Off-nominal rolls are restricted to less than approximately 5 degrees when the U1-to-sun angle is between 50 and 90 degrees, less than 30 degrees when the angle is between 90 and 178 degrees, and it is unlimited between 178 and 180 degrees. (Note that in order to achieve an anti-sun pointing of 178-180 degrees the target must lie in or near the plane of the Earth's orbit.)

Observations requiring a certain ORIENT for a target at a particular time may not be feasible because the required off-nominal roll angle may be outside the allowed limits. The Visit Planner in the Phase II mode of the Astronomer's Proposal Tool (APT) software can be used in such cases to assess the feasibility of the observations. Please contact help@stsci.edu if you need assistance.

2.5 Data Storage and Transmission

The Operations and Engineering Division at STScI constructs the *HST* observing schedule and the actual command loads to be sent to the telescope. Communications with the spacecraft are performed via the Tracking and Data Relay Satellite System (TDRSS) which consists of a set of satellites in geosynchronous orbit. The TDRSS network supports many spacecraft in addition to *HST*. Therefore the use of the network, either to send commands or return data, must be scheduled. Because of limited onboard command storage capacity and TDRSS availability, the command sequences for *HST* observations are normally uplinked approximately once every 8 hours. *HST* then executes the observations automatically. Data are downloaded ten to twenty times per day depending on the observing schedule.

2.5.1 Real-time Contact Requests

Observers at STScI can interact in real-time with *HST*, usually in support of target acquisition pointing adjustments. There are two components to this interaction; data transmission downlink and vehicle/instrument command uplink. The real-time data downlink typically involves expediting the transmission of an *HST* image for determining a pointing correction for a subsequent observation. The real-time mode for transmitting this data is a limited resource that restricts scheduling opportunities since the data collection must occur at the same time that *HST* has high data rate communications with the ground. These opportunities may not coincide with other absolute timing requirements of the science observation itself or the request may simply be an unnecessary restriction in general. The real-time uplink component is less restrictive in that it simply must occur before the observation it is intended to support. However, it is more difficult to find scheduling opportunities for real-time contact requests in general (see Section 5.2.2). Observers who think they may require real-time support for target acquisitions or other reasons should discuss their needs and the implications for their program with STScI.

2.5.2 Onboard Data Storage

HST currently uses large capacity Solid State Recorders (SSRs) to store science data before transmission to the ground. Except when real-time access is required, most *HST* observations are stored to the SSR and read back to the ground several hours later. Some science programs requiring very high data-acquisition rates cannot be accommodated because the instruments would generate more data than either the links or ground system could handle (see Section 6.2.2).

CHAPTER 3:

Telescope Performance

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3.1 Optical Performance

Because the primary mirror has about one-half wave of spherical aberration, the Optical Telescope Assembly (OTA) did not achieve its design performance until after the first servicing mission in December 1993 when corrective optics were installed for the science instruments (SIs). From this time on, the detectors of all SIs (with the exception of the FGSs) have viewed a corrected beam, either via external corrective optics (COSTAR) or via internal optics (for the second and third-generation instruments). COSTAR was removed from the Telescope during SM4 in May 2009 and as of this mission all onboard instruments have internal corrective optics. Table 3.1 gives a summary of general OTA characteristics.

Table 3.1: *HST* Optical Characteristics and Performance

Design	Ritchey-Chretien Cassegrain
Aperture	2.4 m
Wavelength Coverage	From 110 nm (MgF_2 limited) to ~ 3 μm (self-emission limited)
Focal Ratio	*f* /24
Plate Scale (on axis)	3.58 arcsec/mm
PSF FWHM at 5000Å	0.043 arcsec
Encircled Energy within 0.1" at 5000Å	87% (60%-80% at the detectors)

Because each SI has unique characteristics, the actual encircled energy is instrument dependent and may also vary with observing strategy. The *HST* Instrument Handbooks (see Section 1.3) should be consulted for instrument-specific point spread function (PSF) characteristics over various wavelength ranges. The Tiny Tim software tool, developed at STScI by John Krist, with support from Richard Hook at the ST-ECF, can be used to simulate the PSFs of several *HST* instruments. It is available for download from the Tiny Tim Web page. Tiny Tim simulated PSFs coarsely match observations because transient focus changes in *HST* and other effects limit the level of agreement. Therefore, for many types of science, PSF subtraction using Tiny Tim models is inadequate.

3.2 *HST* Guiding Performance

HST's Pointing Control System (PCS) has two guiding modes available. The default guide mode uses Fine Guidance Sensors (FGSs) to provide high precision pointing control by using guide stars to actively control the telescope pointing. However, the telescope pointing can also be controlled using the rate-sensing gyroscopes.

3.2.1 FGS - Dual Guide Star Acquisitions

The default operational practice is to schedule observations using Dual Guide Star mode. In a Dual Guide Star Acquisition, two FGSs lock onto separate guide stars. The combined pointing information is used to control the pitch, yaw, and roll axes of the telescope (by contrast to ground-based telescopes, which generally only use one guide star). Dual Guide Star Acquisition times are typically 6 minutes. Re-acquisitions following interruptions due to Earth occultations take about 5 minutes. This pointing control method was designed to keep telescope jitter below 0.007" rms, which is now routinely achieved. A drift of up to 0.05" may occur over a timescale of 12 hours and more and is attributed to thermal effects as the spacecraft and FGSs are heated or cooled. As a result, observers planning extended observations in 0.1" or smaller STIS slits should execute a target peakup maneuver every 4 orbits (see Section 6.4.2).

3.2.2 FGS - Single Guide Star Acquisitions

In cases where two suitable guide stars are not available, a single guide star acquisition can be used. The translational motion of the *HST* is then controlled by a guide star in one of the FGSs, while the roll motion is controlled by the gyros. Therefore, a gyro drift will be present that is approximately 1.5 mas/sec of roll angle around the guide star. This introduces a translational drift across the target, the exact size of which depends on the roll drift rate and distance from the single guide star to the instrument aperture (target) in the field-of-view (see Figure 2.2). Note however that the gyro drift builds up through occultations and typically limits a visit duration to a few orbits.

There are also occasions when a dual guide star acquisition is planned, but one of the guide stars cannot be acquired. In this case, the Pointing Control System (PCS) will usually carry out the observations using single FGS guiding. A description of this can be found at:

http://www.stsci.edu/hst/observatory/pointing/obslog/OL_7.html

under the header "Single FGS Pitch and Yaw plus Gyro Roll Control" in which a specific application to the case of WFPC2 is discussed. More details on single guide-star guiding issues, particularly those that require very accurate knowledge of the PSF (including coronagraphic programs and astrometric programs) or accurate sub-pixel dithering can be found at:

http://www.stsci.edu/hst/acs/faqs/guide_star.html

and in the *ACS Instrument Handbook* where complimentary examples for the case of ACS are discussed. The typical translational drift rates in single-star guiding will be of similar magnitude for the other instruments. Most science programs will not be adversely affected, because the drift rates are generally small.

3.3 *HST* Observing Efficiency

HST's "observing efficiency" is defined as the fraction of the total time that is devoted to acquiring guide stars, acquiring astronomical targets, and exposing on them. The main factors that limit the observing efficiency are

- The low spacecraft orbit, resulting in frequent Earth occultation of most targets
- Interruptions by passages through the South Atlantic Anomaly
- The number of user-constrained visits
- The relatively slow slew rate

In recent cycles, the average observing efficiency in three-gyro mode had been around 50%. However, that value dropped to < 45% in two-gyro mode. The efficiency has indeed returned to the previous three-gyro mode levels, as it had been expected, once the three-gyro mode was restored for this Cycle. Of the usable observing time, about 90% is allocated to science observations, with the remainder devoted to calibration and engineering observations ($\lesssim$10%), and repeats of failed observations (~2%).

CHAPTER 4:

Cycle 18 Scientific Instruments

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4.1 Wide Field Camera 3 (WFC3)

This camera provides ultraviolet, optical and near infrared imaging through two independent channels. It was installed in May 2009 and replaced the WFPC2. The two channels can not be operated simultaneously, although they can be operated sequentially within the same orbit. Their location in the *HST* field-of-view can be seen in Figure 2.2

The wide-field ultraviolet-visible channel, the **WFC3/UVIS,** is a high throughput, panchromatic camera with a field-of-view of 162" x 162" and operates from 200-1000 nm. The total system throughput with this camera is 28% at 600 nm, see Figure 4.1. The detector is a pair of butted, 2K by 4K, thinned and backside-illuminated, Marconi (now e2v Ltd.) CCDs with an ultraviolet optimized anti-reflective coating and 15 x 15 μm pixels. The plate scale is 0.04 arcsec/pixel. In addition to wavelength optimization, the primary differences between the WFC3 and ACS CCDs include a lower read noise (3 e^- for WFC3, 5 e^- for ACS) and a smaller interchip gap (465 μm rather than 750 μm). The UVIS channel has 62 broad-, medium-, and narrow-band filters and one grism.

The wide-field high-throughput infrared channel, the **WFC3/IR,** has a field-of-view of 123" x 136" over the wavelength range 900-1700 nm. The total system throughput with this camera is 50% at 1600 nm, see Figure 4.1. The detector is a 1K by 1K HgCdTe Teledyne array with 18 x 18 µm pixels. The plate scale is 0.13 arcsec/pixel. The detector has 12.5 e- r.m.s. read noise in a 16-sample non-destructive readout sequence, or 22 e- r.m.s. read noise in the difference of two samples (a Correlated Double Sample). This is better than the NICMOS performance, which achieves 26 - 29 e- r.m.s. in the difference of two samples. The IR channel has 15 broad-, medium-, and narrow-band filters and two grisms.

WFC3 has a slitless imaging spectroscopic modes in both channels and 5 UVIS quad filters as described in Section 4.7.2.

4.2 Near Infrared Camera and Multi-Object Spectrometer (NICMOS)

This camera provides near infrared imaging through three independent channels. NICMOS was installed in February 1997 and has operated with a cooling system since March 2002. While the NICMOS cryocooler was not operating from September 2008 to August 2009, it was functioning nominally prior to the SI C&DH failure on the morning of October 22, 2009. NICMOS will be offered in this cycle once restarted as expected. The three channels provide adjacent but not spatially contiguous fields-of-view of different image scales; they each cover the same wavelength range from 800-2500 nm. Their location in the *HST* field-of-view can be seen in Figure 2.2. The foci of NIC1 and NIC2 are close enough that they can be used simultaneously, whereas NIC3 should be used by itself. NICMOS is expected to be superseded by the WFC3 for most infrared imaging, except for a few specialty or unique modes.

The wide field channel, the **NICMOS Camera 3 (NIC3),** has the lowest spatial resolution of the three channels with a 51.2" x 51.2" field-of-view. The detector is a 256 x 256 HgCdTe array with 40 x 40 µm pixels. The plate scale is 0.2 arcsec/pixel. The camera does not provide diffraction-limited imaging and is operated slightly out of focus. The camera has 19 filters and one blank on a single filter wheel. Well-dithered observations with the NIC3 should lead to a reconstructed PSF FWHM of approximately 0.24 arcsec at 1.6 µm, increasing slightly with wavelength.

The intermediate field channel**,** the **NICMOS Camera 2 (NIC2)** has a 19.2" x 19.2" field-of-view. The detector is a 256 x 256 HgCdTe array with 40 x 40 µm pixels. The plate scale is 0.075 arcsec/pixel. The camera provides diffraction-limited imaging at 1.75 µm and longer. The camera has 19 filters and one blank on a single filter wheel. Well-dithered observations with the NIC2 should lead to a reconstructed PSF FWHM of approximately 0.19 arcsec at 1.6 µm, increasing slightly with wavelength.

The narrow field channel, the **NICMOS Camera 1 (NIC1)** has the highest spatial resolution of the three with an 11" x 11" field-of-view. The detector is a 256 x 256 HgCdTe array with 40 x 40 µm pixels. The plate scale is 0.043 arcsec/pixel. The camera provides diffraction-limited imaging longward of 1 µm. The camera has 19 filters and one blank on a single filter wheel. Well-dithered observations with the NIC1 should lead to a reconstructed PSF FWHM approximately 0.14 arcsec at 1.6 µm, increasing slightly with wavelength.

In the near-infrared, NICMOS is unique in providing imaging polarimetry (Section 4.7.1) and coronagraphy (Section 4.7.3). NICMOS also provides *HST* only capabilities longward of 1700 nm including access to the Pα line and K band. Furthermore the ability to defocus the NICMOS grisms has enabled spectroscopy of bright targets. Both WFC3 and NICMOS have grisms for slitless spectroscopy (Section 4.7.2).

4.3 Advanced Camera for Surveys (ACS)

Only the Wide-Field Channel (WFC) and the Solar-Blind Channel (SBC) are operational and available to observers. A repair to ACS was performed during SM4 and the High Resolution Channel (HRC) was not recovered. Observers should consult the ACS Instrument Handbook and ACS Web Page for current information on performance.

This camera provides ultraviolet and optical imaging through three independent channels. ACS was installed during SM3B in March 2002. This camera provides ultraviolet and wide-field optical imaging through two independent channels that have adjacent but not contiguous fields of view. The locations of these channels in the *HST* focal plane are shown in Figure 2.2. The ultraviolet and wide-field channels can be operated concurrently.

The wide field channel, the **ACS/WFC,** provides high throughput, wide-field, visible imaging. The camera has a 202" x 202" field-of-view from 370 to 1100 nm. The total system throughput with this camera is 42% at 600 nm (see Figure 4.1). The WFC detector is a pair of butted, 2K by 4K, thinned and backside-illuminated, SITe CCDs with a red optimized coating, a long-wavelength halo fix and 15 x 15 µm pixels. The plate scale is 0.050 arcsec/pixel. The WFC PSF is critically sampled at 1160 nm and undersampled by a factor 3 at 370 nm. Well-dithered observations with the WFC should lead to a reconstructed PSF FWHM of 0.1" to 0.14".

The solar blind channel, the **ACS/SBC,** is optimized for high resolution, solar-blind far-UV imaging. The camera has a 34" x 31" field-of-view from 115 to 170 nm and a peak efficiency of 6% (see Figure 4.1). The detector is a solar-blind CsI Multi-Anode

Microchannel detector Array (MAMA) with 25 x 25 µm pixels. The plate scale is 0.032 arcsec/pixel. The channel uses the same optical train as the HRC and is comparable in performance to the FUV MAMA of STIS.

Information on the ACS/HRC can be found in Appendix C, Legacy Instruments.

In addition to these prime capabilities, ACS also provides imaging polarimetry (Section 4.7.1) and slitless spectroscopy (Section 4.7.2).

4.4 Fine Guidance Sensor (FGS)

There are three FGSs onboard *HST*. One, called FGS1R, is used for astrometry. FGS1R was installed in 1997. As a scientific instrument, the FGS1R offers accurate relative astrometry and high spatial resolution. There are two modes of operating the FGS.

In the so-called **Position mode (POS)** the FGS measures the relative positions of objects in its 69 square arcminute FOV with a precision of ~ 1 milliarcsec (mas) per observation. Position mode observing is used to determine the relative parallax, proper motion, and reflex motion of single stars and binary systems. Multi-epoch programs have resulted in measurements accurate to 0.3 mas or less.

In the so-called **Transfer mode (TRANS)** the 5" x 5" instantaneous field-of-view of the FGS is scanned across an object to obtain an interferogram with high spatial resolution. (This is conceptually equivalent to an imaging device that samples an object's PSF with 1 mas pixels.) Hence, Transfer mode observing is used to measure the angular size of extended objects or to resolve binary systems and measure the separation, position angle, and relative brightness of its components. FGS1R can resolve close binary systems with angular separations of only 8 mas and magnitude differences of less than 1 mag. Systems with delta mag = 4 can be resolved provided the separation of the stars is larger than ~30 mas.

In either mode, the FGS yields 40 Hz photometry with a relative precision of about 1 milli-magnitude. Objects over the dynamic range of $3 < V < 17$ can be observed.

4.5 Cosmic Origins Spectrograph (COS)

The Cosmic Origins Spectrograph (COS) is an ultraviolet spectrograph designed to optimize observations of point sources. It was installed in SM4 and replaced COSTAR. COS is designed to be a very high throughput instrument, providing medium to low resolution ultraviolet spectroscopy. The instrument has two channels for ultraviolet spectroscopy.

The far-ultraviolet channel**,** the **COS/FUV,** uses a single optical element to disperse and focus the light onto a crossed-delay-line (XDL) detector; the result is high ultraviolet sensitivity from about 110 - 200 nm with R ~ 2500 and R ~ 20,000 modes (please see the *COS Instrument Handbook* for more detailed information on the resolving power of the FUV channel). This detector, although new to *HST*, has heritage from the FUSE spacecraft. The active front surface of the detector is curved and to achieve the length required to capture the entire projected COS spectrum, two detector segments are placed end-to-end with a small gap between them. Each detector segment has an active area of 85 x 10 mm digitized to 16384 x 1024 pixels, and a resolution element of 6 x 10 pixels.

The FUV channel has three gratings. The G140L grating allows nearly complete coverage of the FUV wavelength range in a single exposure at a resolving power R ~ 2500 - 3000. The G130M grating provides two 14 nm long spectra with a 1.7 nm gap in a single exposure, over the wavelength range 115 - 145 nm, while the G160M grating provides two 17 nm long spectra with a 2.1 nm gap in a single exposure over the wavelength range 140 - 175 nm. These gaps can be covered by two separate exposures offset in wavelength.

The near-ultraviolet channel**,** the **COS/NUV,** employs a 1024 x 1024 pixel Cs_2Te MAMA detector that is essentially identical to the STIS/NUV-MAMA albeit with a substantially lower dark count than the STIS detector. Four gratings may be used for spectroscopy. Portions of the first-order spectra from the gratings are directed onto the detector by three separate flat mirrors. Each mirror produces a single stripe of spectrum on the detector. For low-dispersion grating G230L, one or two first-order spectrum stripes are available, each covering ~40 nm of the entire 170-320 nm range at resolving power R ~ 1550-3000, depending upon wavelength. For high-dispersion gratings G185M, G225M, and G285M, three non-contiguous-in-wavelength stripes of 3.5 nm are available in each exposure at resolving powers of 16,000 to 24,000. Panchromatic (170-320 nm) images of small fields (< 2 arcsec) may also be obtained at ~0.05 arcsec resolution in imaging mode.

Both the FUV and NUV channels offer ACCUM and TIME-TAG observing modes. In TIME-TAG mode, which is the default observing mode, the time resolution is 32 msec.

4.6 Space Telescope Imaging Spectrograph (STIS)

The Space Telescope Imaging Spectrograph was installed in February 1997, and provides ultraviolet and optical spectroscopy and imaging through three channels. The STIS can be used to obtain spatially resolved, long-slit (or slitless) spectroscopy over the 115 - 1030 nm wavelength range at spectral resolving power of R ~ 500 to 17,500; and echelle spectroscopy over the 115 - 310 nm wavelength range at spectral resolving powers of R ~ 30,000 and 114,000, covering broad spectral ranges of $\Delta\lambda$ ~ 80 nm and 20 nm, respectively. STIS can also be used for optical and solar-blind ultraviolet imaging. Three detectors, each with a 1024 x 1024 pixel format, support spectroscopy and imaging as follows.

The **STIS/FUV-MAMA** far ultraviolet channel uses a solar-blind, CsI, Multi-Anode Microchannel detector Array (MAMA), with a field-of-view 25" x 25", a plate scale of 0.025 arcsec/pixel, and covers the wavelength region from 115 - 170 nm.

The **STIS/NUV-MAMA** near ultraviolet channel uses a Cs_2Te MAMA detector with the same FOV and plate scale, and covers the 160 - 310 nm wavelength region.

For the 165 - 1100 nm optical wavelength region, the **STIS/CCD** detector is a thinned and backside-illuminated SITe CCD with a near-ultraviolet optimized coating. The field-of-view is 52" x 52" and the plate scale is 0.05 arcsec/pixel.

The MAMA detectors can be used in ACCUM or TIME-TAG modes, with the latter supporting time-resolutions down to 125 µsec, and the CCD is able to be cycled in ~ 20 seconds when using small subarrays. The CCD and the MAMAs also provide coronagraphic spectroscopy in the visible and ultraviolet. Coronagraphic CCD imaging is also available (see next section). Each of the STIS detectors can also be used for imaging observations, although only limited filter choices are available.

Summary of STIS changes after SM4:

STIS was successfully repaired during SM4. Capabilities are very similar to those prior to the 2004 failure. Overall sensitivities have declined by only a few percent.

However, the STIS CCD has continued to accumulate radiation damage. We estimate that the mean STIS CCD dark current will be 0.015 e-/pixel/s during Cycle 18. Charge transfer efficiency (CTE) declines can also have a strong effect on faint sources observed with the STIS CCD. Users should remember that the STIS ETC does not correct for CTE losses. They should instead consult the *STIS Instrument Handbook* or use the script provided at:

http://www.stsci.edu/hst/stis/software/scripts/cteloss_descrip.htm

to estimate these losses.

When initially recovered after SM4, the NUV MAMA showed a much larger dark current than had previously been seen, although this excess is slowly declining. For planning purposes users should assume that the NUV dark current during Cycle 18 will have value of 0.005 counts/pixel/s, but this is highly uncertain and the actual value may be significantly different.

For further details regarding STIS capabilities after SM4, and for any late breaking updates see the Cycle 18 STIS IHB and the STIS Web site at STScI.

4.7 Additional Observing Modes

4.7.1 Imaging Polarimetry

ACS/WFC provides imaging polarimetry at 0^o, 60^o, and 120^o relative polarization angles. NICMOS/NIC1 provides imaging polarimetry from 800 - 1300 nm and NIC2 provides imaging polarimetry from 1900 - 2100 nm, both with 0^o, 120^o, and 240^o relative polarization angles. WFC3, STIS and COS do not have a polarimetric capability.

4.7.2 Slitless Imaging Spectroscopy

In the **ultraviolet**, <350 nm, there are a number of choices. ACS/SBC has two prisms providing R ~ 100 spectroscopy (at 121 nm) from 115-170 nm. The WFC3/UVIS has a grism for R ~ 70 spectroscopy from 200 - 400 nm, and the STIS/NUV has a prism covering the range 115 - 300 nm with R ~ 2500. In addition, any 1st order STIS mode can be used for large aperture slitless spectroscopy over a 52"x52" FOV (STIS CCD gratings) or a 25"x25" FOV (STIS MAMA 1st order gratings).

In the **optical**, ACS/WFC covers 550 - 1050 nm with a grism at R ~100. The STIS CCD also has a number of gratings, which can be used for slitless spectroscopy over a 52"x52" FOV at wavelengths ranging from as short as 170 nm to as long as 1020 nm.

In the **near-infrared**, 800 - 2500 nm, WFC3/IR has a grism with R ~ 210 covering 800 - 1150 nm, and a grism with R ~ 130 covering 1100 - 1700 nm. NICMOS/NIC3 has three grisms with R ~ 200 to cover the wavelength region from 800 to 2500 nm in three sections.

Ramp Filters: ACS has a set of ramp filters covering the wavelength range 310 - 1071 nm at 2% and 9% bandwidth. There are five ramp units which each have an inner, middle, and outer segments. The ACS/WFC can use all three segments, providing 15 ramp filters.

Quad Filters: WFC3/UVIS contains 5 quad filters. Each is a 2 x 2 mosaic of filter elements with each quadrant providing a different bandpass for narrow band line or continuum measurements.

4.7.3 Coronagraphy

NICMOS/NIC2 provides corrected beam coronagraphy through a 0.8" effective diameter occulting hole. WFC3 does not have a coronagraphic capability. STIS aperture bars allow spectroscopic coronagraphy, while the STIS 50CORON aperture provides various wedges and bars that can be used for unfiltered imaging coronagraphy with the STIS CCD.

4.7.4 Observations with Two Instruments - Parallel Observing

We encourage observers to submit programs that make use of simultaneous observations with two or more cameras. This can greatly increase the scientific value of individual programs and the public archive. There are two ways to obtain parallel observations.

Coordinated Parallels:

As the name implies, coordinated parallel observations afford the individual observer the ability to use multiple instruments simultaneously and in a way that optimizes the telescope pointing (e.g., dither patterns or mosaicing) and exposure and readout times to satisfy the goals of both the primary and parallel science components of a single science program.

Pure Parallels:

Pure parallel observations are proposed independently of any primary GO science program and are slightly more restrictive in the number of allowed parallel/primary instrument combinations than are coordinated parallels. The approach to pure parallel observing, which was implemented for Cycle 17, will identify the parallel scheduling opportunities that are inherent to the accepted set of primary COS and STIS spectrographic observations for the cycle. Accepted WFC3 and/or ACS pure parallel observations are then matched and structured to schedule simultaneously with those COS and STIS primary observations. The matching and structuring of parallel to prime observations at the start of the observing cycle is intended to improve the execution rate for all accepted pure parallel programs.

Policies and Procedures:

The policies for coordinated and pure parallel observing, including allowed instrument usage, are found in the Cycle 18 Call for Proposals.

The detailed descriptions of the coordinated and pure parallel observing modes, guidelines for developing a proposal using these modes, and how they are implemented and scheduled, are found in the Parallel Observations User Information Report and the individual instrument handbooks.

4.8 Instrument Comparisons

With the success of Servicing Mission 4, *HST* observers are presented with many choices of instruments. In many situations, the observer will have to make a selection between complementary cameras, for example, ACS/WFC and WFC3/UVIS, or complementary spectrographs, COS and STIS. Both STIS and ACS have continued to age in the high-radiation environment since they were last used. For STIS, a "Summary of changes after SM4" is to be found at the end of Section 4.6. The CTE of ACS/WFC has indeed degraded to the level expected for 7+ years aboard *HST*. The damaging effects of continuous radiation exposure on the CCDs are unavoidable, regardless of whether the camera is operating or not. Although the CTE itself cannot be improved, its detrimental effects on photometry can be mitigated by positioning targets close to the corners (i.e., readout amplifiers) of the CCDs. Please consult the Cycle 18 Announcement Web page for up to date information on the status of *HST* instrumentation.

In this section, we make some general comparisons between instruments and their modes to help provide some basic criteria for specific instrument choice. Where the choice is not immediately clear, the observer should read through the relevant sections of the Instrument Handbooks and carry out modeling of the astronomical fields using tools provided. For this cycle, new Exposure Time Calculators (ETCs) for all instruments (except NICMOS) are available and can be found at:

http://www.stsci.edu/hst/observatory/etcs/ .

They use a new computing tool called PySynphot, in place of the previously used synphot, and access reference files updated with the most recent data available from SMOV. For more details on the new ETCs, please refer to the Web page at:

http://www.stsci.edu/hst/observatory/etcs/etc_user_guide/transition_py_syn.html .

4.8.1 *HST* Imaging

The cameras we consider in this section are WFC3, ACS, NICMOS and STIS. Decisions will be made based largely on wavelength and areal coverage, spatial resolution, sensitivity, and the availability of specific spectral elements or observing modes, to accomplish the proposed science. In Figures 4.1 to 4.4 we have provided a set of plots which compare throughput and discovery efficiency for the main cameras, based on SMOV data for WFC3 (for the IR throughputs, please refer to WFC3 ISR 2009-30 and for the UVIS, WFC3 ISR 2009-31). These figures will help to illustrate the recommendations below.

In the far-ultraviolet (FUV < 200 nm) the ACS/SBC is more sensitive and has more filters than the STIS FUV-MAMA and is the recommended choice. In the near-ultraviolet (NUV ~ 200 - 350 nm) the WFC3/UVIS has a superior field-of-view and sensitivity than STIS/NUV-MAMA and is the recommended choice. Table 4.1 contains a detailed comparison.

Table 4.1: Imaging at Near-UV Wavelengths (200 - 350 nm)

	WFC3/UVIS	STIS/NUV-MAMA
FOV Area (arcsec2)	162" x 162" (26183)	25" x 25" (625)
Broadband Throughput @ 230, 330 nm	0.08, 0.19	0.026, 0.002
Pixel Scale (arcsec)	0.040	0.025
Number of Pixels	4k x 4k	1k x 1k
Read Noise (e-)	3.0-3.1	None
Dark Current	$4.0x10^{-4}$ (e-/pix/s)	0.005 (cnt/pix/s)[1]
Number of Filters	13 10 full-field 3 quad	9 8 full-field (inc. 2 ND), 1 quad ND

1. After SM4, the phosphorescent window glow in the STIS NUV MAMA detector was found to average about 0.013 cnt/pix/s, or about ten times higher than had been seen before the 2004 failure. This excess dark current is coming down very slowly, and the dark current that the NUV MAMA detector will have during Cycle 18 is highly uncertain.

WFC3/UVIS has a higher throughput than any *HST* instrument over the wavelength range extending from its blue cutoff (at 200 nm) to ~400 nm. Beyond this limit, the choice of which *HST* instrument is best suited for users depends on the details of the science requirements. Although the absolute throughput of ACS is higher at optical wavelengths, the highest WFC3 efficiency gains in on-orbit observations also occur at 400-700 nm, and therefore the gap between the two instruments has been closed significantly. Specifically, some of the primary science observations with *HST* require several orbits where signal is coadded over multiple exposures. Relative to ACS/WFC, WFC3 has smaller pixels by 20%, a lower readnoise by 50%, negligible CTE corrections, and a much lower dark current. Combined with our new efficiency measurements, the ability to better sample the PSF and naturally beat down the noise through multiple exposures can make the WFC3 the preferred instrument for even broadband F606W and F814W observations of faint sources. The choice between the two instruments will require careful predictions from the respective ETCs, factoring in detailed observational setup. Of course, WFC3 contains many more filters over its complete wavelength range than ACS/WFC, yet ACS offers a 50% larger field of view, both considerations potentially important for users.

In the near-infrared (800 - 2500 nm), the WFC3/IR has superior throughput and a much larger field-of-view than NICMOS, and the data should be easier to reduce and calibrate, due to accurate bias subtraction made possible by the presence of reference pixels. WFC3/IR is the clear recommendation for most near-infrared observing. However, NICMOS/NIC1 and NIC2 do have smaller pixels than WFC3/IR and the wavelength range of NICMOS does extend to 2500 nm, while WFC3/IR coverage ends at 1700 nm. Table 4.3 contains a detailed comparison.

Table 4.2: Imaging at Optical Wavelengths (350 - 1000 nm).

	WFC3/UVIS	**ACS/WFC**
FOV Area (arcsec2)	162" x 162" (26183)	202" x 202" (40804)
Broadband Throughput[1] @ B,V, I, z	0.23,0.28, 0.16, 0.09	0.34,0.41, 0.36, 0.20
Pixel Scale (arcsec)	0.040	0.049
Number of Pixels	4k x 4k	4k x 4k
Read Noise (e-)	3.0-3.1	5
Dark current	$4.0x10^{-4}$ (e-/pix/s)	$6.2x10^{-3}$ (e-/pix/s)
Number of Filters	49 32 full-field 17 quad	27 12 full-field 15 ramp

1. Average throughput at 10 nm bandpass at the pivot wavelength (V=F606W; I=F814W; z=F850LP).

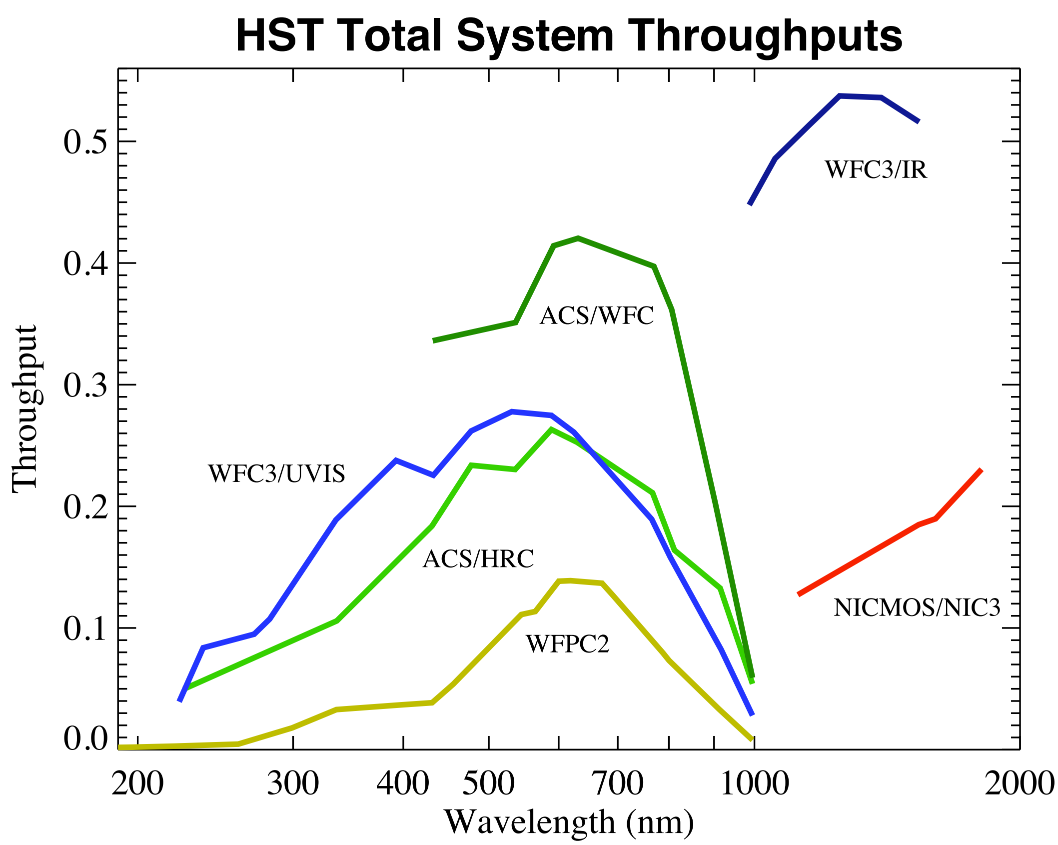
Table 4.3: Imaging at Near-Infrared Wavelengths (800 - 2500 nm).

	WFC3/IR	**NIC3**	**NIC2**	**NIC1**
FOV Area (arcsec2)	123" x 136" (16728)	51" x 51" (2601)	19" x 19" (361)	11" x 11" (121)
Broadband Throughput @ 1.1, 1.6 µm	0.49, 0.50	0.13, 0.20	0.14, 0.20	0.12, 0.18
Wavelength Range	0.9- 1.7 µm	0.8 - 2.5 µm	0.8 - 2.5 µm	0.8 - 1.8 µm
Pixel Scale (arcsec)	0.13	0.200	0.075	0.043
Number of Pixels	1014 x 1014	256 x 256	256 x 256	256 x 256
Read Noise (e-)	12.5	29	26	26
Number of Filters	15	16	19 16 standard, 3 polarizers	19 16 standard, 3 polarizers

In the following four figures, we present a graphical comparison of the *HST* imaging detectors with respect to several useful parameters: system throughput, discovery efficiency, limiting magnitude, and extended source survey time.

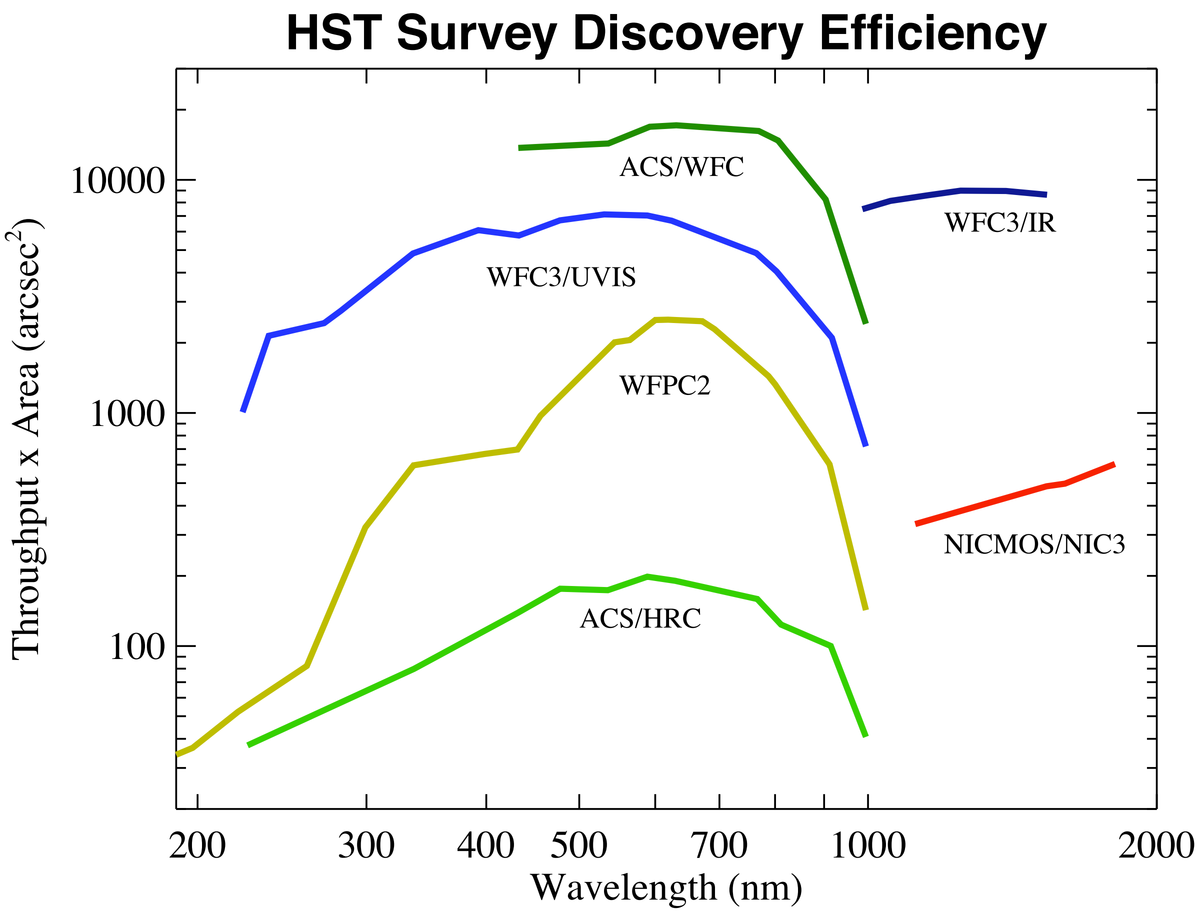
System throughputs as a function of wavelength are shown in Figure 4.1. The plotted quantities are end-to-end throughputs, including filter transmissions calculated at the pivot wavelength of each broad-band filter.

Figure 4.1: *HST* Total System Throughputs



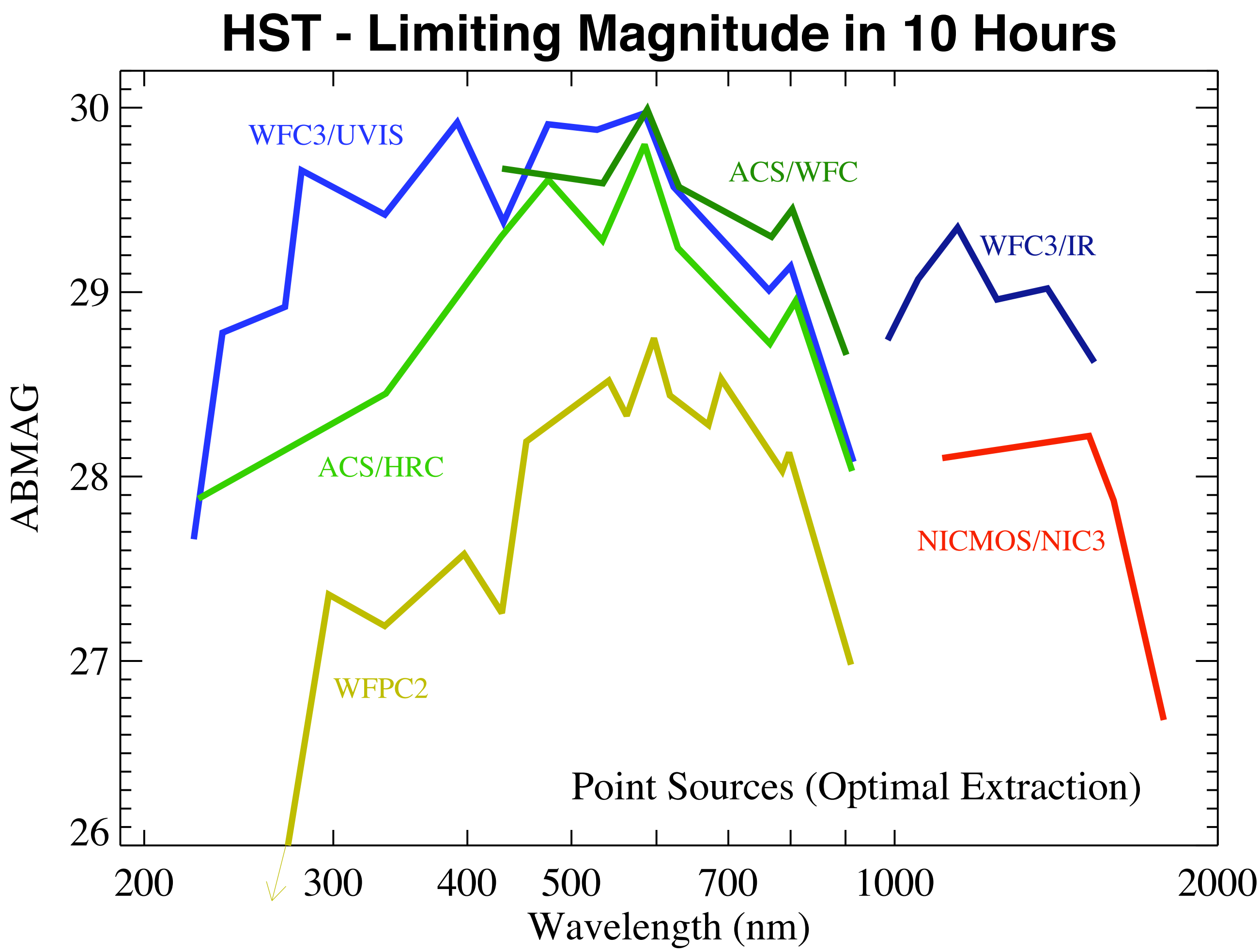
The discovery efficiencies of the cameras, defined as the system throughput multiplied by the area of the field-of-view, are shown in Figure 4.2.

Figure 4.2: *HST* Survey Discovery Efficiencies



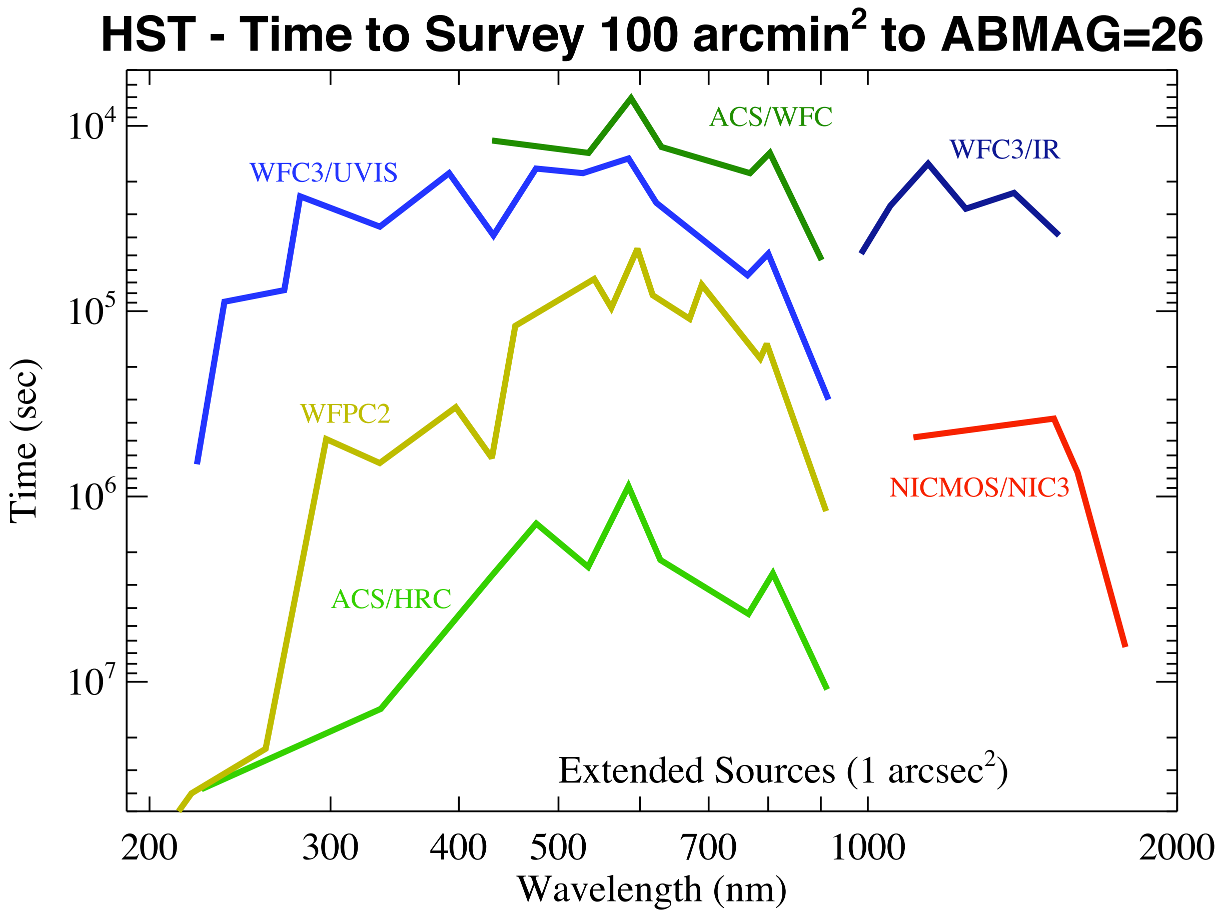
The point-source limiting magnitude achieved with a signal to noise of 5 in a 10 hour long exposure with optimal extraction is shown in Figure 4.3.

Figure 4.3: Point-Source Limiting Magnitude



The next figure, Figure 4.4, shows the extended-source survey time to attain ABMAG=26 in an area of 100 arcmin^2.

Figure 4.4: Extended-Source Survey Time



4.8.2 Spectrographs

In the far-ultraviolet (FUV ~ 115 to 205 nm), COS is more sensitive than STIS by factors of 10 to 30, while in the near-ultraviolet (NUV ~ 17 to 320 nm) COS sensitivity is two to three times that of STIS. COS also has a unique, but limited, capability in the FUV spectral region shortward of 115 nm extending to ~91 nm - please refer to the COS Instrument Handbook for important considerations concerning COS observations in this wavelength range. COS is optimized for observations of faint point source targets, so it will be the instrument of choice for such objects. Its aperture is 2.5" in diameter. COS FUV spatial resolution is limited to 1", while the COS NUV spatial resolution is approximately 0.05". However for sources larger than approximately 1" perpendicular to the dispersion direction, portions of the spectrum may overlap on the NUV detector. Therefore, when spatial resolution is required, STIS will usually be the preferred instrument. STIS 1st order NUV and FUV MAMA modes have spatial resolution of about 0.05" over a 25" long slit, while STIS CCD spectral modes

(190-1020 nm) have spatial resolution of about 0.1" with a 52" long slit. COS does not operate in the optical.

STIS high dispersion echelle modes also have significantly higher spectral resolution than COS (100,000 vs. 20,000), which will be essential for some science programs. In addition, the STIS NUV medium resolution echelle mode E230M has a wider wavelength coverage in a single exposure (~80 nm) than does a single COS NUV medium resolution exposure (10 to 12 nm in three discontinuous pieces). Despite the sensitivity advantage of COS in the NUV, when complete coverage of a broad wavelength range is needed, STIS may be a more efficient choice. STIS also has a wider variety of apertures than does COS, including a number of neutral density apertures, and so STIS may be preferred for many UV bright objects.

A useful comparison of COS and STIS at ultraviolet wavelengths is given in Table 4.4.

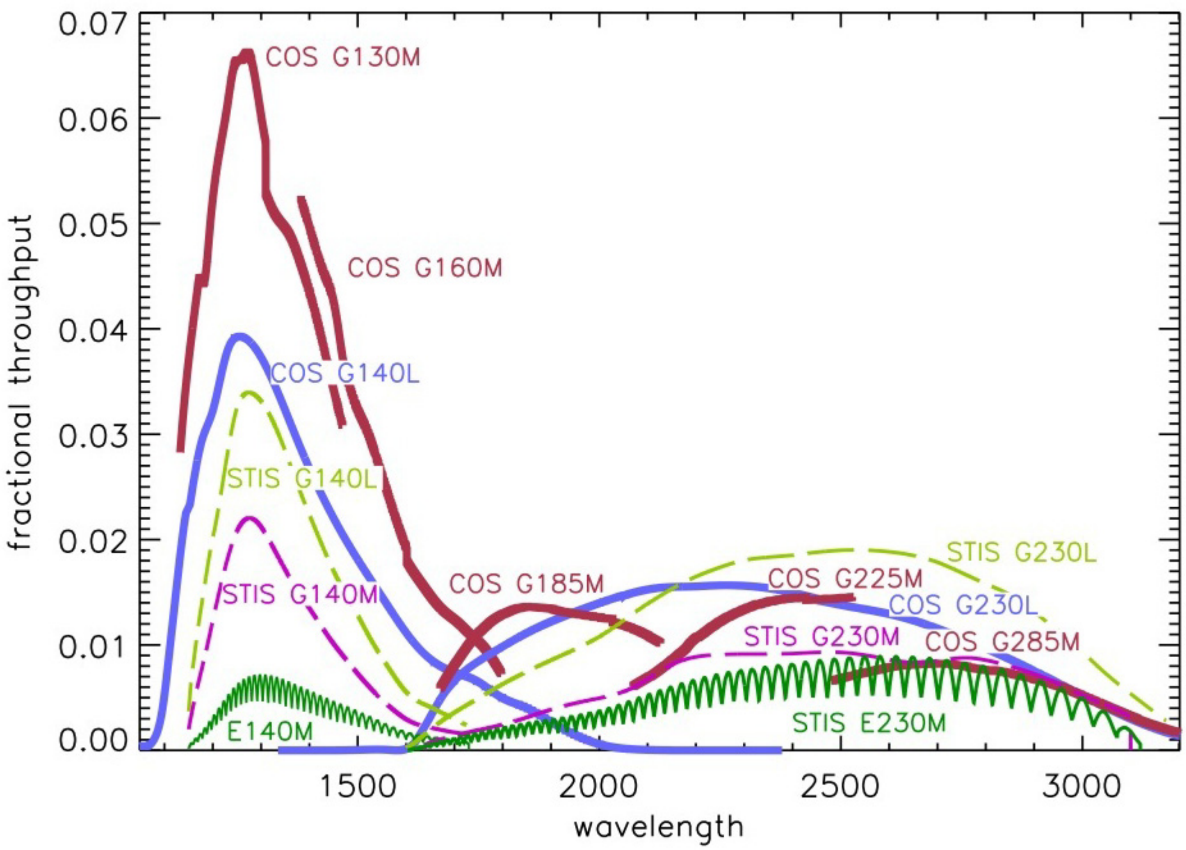
Table 4.4: Spectroscopy at Ultraviolet Wavelengths

		COS/FUV	COS/NUV	STIS/FUV	STIS/NUV
Spectral Coverage (Å)		1150 - 1775 (M) 910 - 2050 (L)	1700 - 3200	1150 - 1700	1600 - 3100
Effective Area (cm^2) @ 1300Å (FUV), 2500Å (NUV)		2800 (M) 2400 (L)	900 (M) 750 (L)	400 (M) 1700 (L)	350 (M) 900 (L)
Resolving Power $R = \lambda/d\lambda$	H M L	N/A 16,000 - 20,000 2400 - 3500	N/A 16,000 - 24,000 1500 - 2800	114,000 10,000 - 46,000 1000	114,000 10,000 - 30,000 500
Number of Pixels Along Dispersion		32768	1024	1024 (2048)	1024 (2048)
Background (cts/s/resel)		5.4×10^{-5}	6.01×10^{-4}	350×10^{-5}	0.03[1]
Background Equivalent Flux ($ergs/cm^2/s/Å$)		$(0.6 - 10) \times 10^{-18}$	$(0.4 - 1.2) \times 10^{-16}$	20×10^{-18}	[1.7(G230L) - 1200 (E230H0] x 10^{-16}

1. After SM4, the phosphorescent window glow in the STIS NUV MAMA detector was found to average about 0.013 cnt/pix/s, or about ten times higher than had been seen before the 2004 failure. This excess dark current is coming down very slowly, and the dark current that the NUV MAMA detector will have during Cycle 18 is highly uncertain.

The throughputs of COS and STIS in the ultraviolet are shown in Figure 4.5. The effect of the *HST* OTA is included. STIS throughputs do not include slit losses.

Figure 4.5: Throughputs for COS and STIS in the FUV and NUV.



CHAPTER 5:

Observing Considerations

In this chapter...

5.1 Bright-Object Constraints / 37
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5.3 Solar System Targets / 40
5.4 Offsets, Patterns, and Dithering / 41

5.1 Bright-Object Constraints

Some of the SIs must be protected against over-illumination; observations that violate these protections cannot be executed and should not be proposed. We emphasize that the constraints discussed below are *safety* constraints; data become affected by bright objects at substantially fainter limits than the safety limits discussed in the following sections. Bright-object related effects include non-linearity, saturation, and residual-image effects. Please consult the *HST* Instrument Handbooks (see Section 1.3) for details.

5.1.1 ACS, COS & STIS

The CCDs on ACS and STIS have no safety-related brightness limits.

The MAMA detectors in the ACS/SBC, COS (NUV), and STIS, and the COS/XDL (FUV) detector, can be damaged by excessive levels of illumination and are therefore protected by hardware safety mechanisms. In order to avoid triggering these safety mechanisms, successful proposers using the above detectors are required to check their targets and fields in detail for excessively bright sources by the Phase II deadline. This can be accomplished using tools available within APT. Exceptions to these Phase II bright-object checks are moving target fields, which must be cleared after the scheduling windows have been established.

The bright object count-rate limits are mode dependent. Specific values are given in the instrument handbooks including example magnitude screening limits for astronomical objects observed in the most commonly used modes. In addition, the Exposure Time Calculators (ETCs), accessible from the *HST* Instruments Web Page, can be used to determine if a particular target and configuration combination exceeds the global or local countrate screening limits.

For the SBC, the V magnitude screening limits are quoted in Section 7.2 of the *ACS Instrument Handbook*. For the STIS MAMAs, these limits are given in Section 7.7 of the *STIS Instrument Handbook*. For the COS XDL and MAMA, screening limits are given in Chapter 4 of the *COS Instrument Handbook*. For objects with strong UV fluxes (e.g., early-type stars), the screening limit can be as faint as V=19. Therefore, proposers using any of these health and safety instrument modes must refer to the relevant instrument handbooks for instructions on performing a detailed analysis for their specific sources, and discuss the results in the Description of the Observations section of the Phase I proposal (see Section 9.2 of the Call for Proposals). Both the targets and other objects in the FOV will have to be cleared during Phase II, but if the field is particularly crowded or if any object in the FOV is known to pose a brightness concern, observers are asked to explain in the Description of Observations section of the Phase I program how they will propose to clear them during Phase II.

Note that for SBC prism spectroscopy, a direct image must be added manually to provide the wavelength calibration, and it will drive the safety issue since the direct filters are more sensitive than the prisms. This image must be included in the Observing Summary (see Section 8.15 of the Call for Proposals) and the safety discussion.

In the case of aperiodic variables that are either known to undergo unpredictable outbursts, or belong to classes of objects that are subject to outbursts, the proposer must determine whether the target will violate the bright object limits during outburst. If a violation is possible, the proposer must outline a strategy that will ensure that the target is safe to observe with COS, STIS/MAMA or ACS/SBC. The observing strategy might include additional observations, obtained over a timescale appropriate to the particular type of variable object, with either *HST* or ground-based telescopes. If *HST* data are to be used for this purpose, the required orbits must be requested in Phase I (see Section 4.1.3 of the Call for Proposals). Further details about these procedures are presented in ACS ISR 06-04. The general policies described there apply to the STIS/MAMA and COS detectors as well, with suitable scaling for the differences in the exact BOP limits for each detector and mode. These limits are described in the individual instrument handbooks.

5.1.2 FGS

Objects as bright as V=3.0 may be observed if the 5-magnitude neutral-density filter (F5ND) is used. Observations of all objects brighter than V=8.0 should be performed with this filter. A hardware limitation prevents the FGS target acquisition from succeeding for any target brighter than V=8.0 (3.0 with F5ND).

5.1.3 NICMOS

There are no safety-related brightness limits for NICMOS. Observers should, however, be aware that saturating the detectors may lead to significant persistent signal in subsequent exposures.

5.1.4 WFC3

There are no safety-related brightness limits for WFC3. Furthermore, over-exposure of UVIS images does not leave persistent signals in subsequent exposures. Saturated IR images do persist and have significant implications for design of observing strategies and data analysis. See the *WFC3 Instrument Handbook* for more information.

5.2 Target Acquisitions

Target acquisition is the procedure used to ensure that the target is in the field-of-view of the requested aperture to the level of accuracy required by the observer. There are several distinct methods of target acquisition; each method has a different approach and different accuracy and will take different amounts of time and resources to complete. The required level of accuracy depends on the size of the aperture to be used to obtain the science data and on the nature of the science program.

5.2.1 Target Acquisition without the Ground System

Blind acquisition

For blind acquisition, guide stars are acquired and the FGSs are used for pointing control. The pointing is accurate to the guide star position uncertainty, which is approximately 0.3" rms, plus the instrument-to-FGS alignment error.

Onboard acquisition

For onboard acquisition, software specific to the scientific instrument centers the fiducial point onto the target. Onboard target acquisitions are needed for COS and STIS spectroscopic observations (except slitless) and all coronagraphic observations with NICMOS and STIS. The WFC3 does not have onboard acquisition capabilities. For specific information on methods and expected pointing accuracies, see the *HST* Instrument Handbooks.

Early acquisition

For early acquisition, an image is taken in an earlier visit and analyzed by the PI. The PI may then update the target coordinates in the Phase II proposal for use with subsequent visits.

5.2.2 Target Acquisition with Ground System Support

Target acquisitions that cannot be accomplished successfully or efficiently via one of the above methods may still be possible with STScI ground system support. This is accomplished by analyzing certain data and calculating and up-linking appropriate pointing corrections to the telescope. An example is a technique to avoid repeating multi-stage target acquisitions. Instruments that require multi-stage target acquisitions in order to center a target in a small aperture as in STIS, for example, consume a large fraction of the viewing time in an orbit. Target acquisition time may be saved if repeated observations of the same target are planned for multiple visits. In this mechanism, engineering and image data are obtained from an initial successful target acquisition. The telescope offset resulting from the acquisition is retrieved from the data and used to bypass the acquisition sequence in repeat visits as long as the guide stars of the initial visit are also used. Request for this support is implicit in the specification of the “Save Offset” and “Use Offset” special requirements in the Phase II proposal.

5.3 Solar System Targets

Objects within the Solar System move with respect to the fixed stars. *HST* has the capability to point at and track moving targets, including planets, their satellites and surface features on them, with sub-arcsecond accuracy. However, there are a variety of practical limitations on the use of these capabilities that must be considered before addressing the feasibility of any particular investigation. Proposals to observe the Moon, for example, will be permitted in Cycle 18. Please consult the Lunar Observations User Information Report (UIR-2007-01) for more information.

HST is capable of tracking moving targets with the same precision achieved for fixed targets. This is accomplished by maintaining FGS Fine Lock on guide stars, and driving the FGS star sensors in the appropriate path, thus moving the telescope so as to track the target. Tracking under FGS control is technically possible for apparent target motions up to 5 arcsec per second. In practice, however, this technique may become infeasible for targets moving more than a few tenths of an arcsec per second.

The track for a moving target is derived from its orbital elements. Orbital elements for all of the planets and their satellites are available at STScI. For other objects, the PI must provide orbital elements for the target in Phase II. The Reuse Target Offset capability (see above) can be used to insert an offset within 3 days of the observation to eliminate “zero-point” errors due to an inaccurate ephemeris.

See Section 4.1.4 of the Call for Proposals for restrictions on observations of Solar System targets.

5.4 Offsets, Patterns, and Dithering

Offsets are routinely used to reposition the target in the instrument field-of-view. The size of the offset is limited by the requirement that both guide stars remain within the respective fields of view of their FGSs. Offsets within single detectors (the most common type) can be performed to within +/–0.003". Offsets that continue across separate visits (when executed with the same guide stars) will typically have an accuracy of ~ 0.05".

Patterns are used to place the telescope at multiple positions to allow for dithering or mosaic construction. Patterns can define a linear, spiral, or parallelogram series of observation points. Patterns can also be combined to produce a more complex series of observation points. In addition, “convenience patterns” have been predefined to represent typical dither and mosaic strategies; for details see the Phase II Instructions document, available from the Phase II Program Preparation Web page. The possible pattern area is limited by the requirement that the same guide stars be used throughout the pattern. This implies a maximum of about 120 arcsec of linear motion.

For most small or medium-sized imaging programs (e.g., up to a few orbits per target/field combination), conventional dither patterns can be used, which generally consist of offsets designed to provide half-pixel subsampling as well as to move bad pixels and inter-chip gaps to different locations on the sky. Larger programs may benefit by considering more complex dithering strategies, to provide, for example, even finer subsampling of the detector pixels. The data can be combined using the MultiDrizzle software provided as part of PyRAF/STSDAS. More details are provided in the *HST MultiDrizzle Handbook*.

In general, undithered observations with the ACS CCD and WFC3 CCD and IR detectors will not be approved without strong justification that such are *required* for the scientific objectives. Otherwise, hot pixels and other detector artifacts will compromise the program and the archival value of the data. Further details about the options and advantages of ACS patterns can be found in the *ACS Instrument Handbook*, the Phase II Proposal Instructions, and the ACS Dither Web page. Information on dithering for WFC3 observations is found in Appendix C of the *WFC3 Instrument Handbook*.

For NICMOS observations, we also strongly recommend observers to make use of dither patterns to enable removal of detector artifacts and provide sub-pixel sampling of the PSF. Further details about the advantages and specifications for NICMOS dither patterns can be found in the *NICMOS Instrument Handbook* and the Phase II proposal Instructions.

STIS CCD observations will also normally benefit from dithering to eliminate hot pixels and improve PSF sampling, although for spectroscopic observations this may in some cases also complicate the data reduction. See the *STIS Instrument Handbook* and the Phase II Proposal Instructions for further details.

CHAPTER 6:

Orbit Calculation for a Phase I Proposal

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6.1 Overview of an Observing Program

6.1.1 General Observer (GO) Programs

Definitions (*HST* Orbits, Visibility Periods, and Visits)

HST GO observing time is counted in terms of *orbits*. Each 96 minute orbit contains a certain amount of useful time when the target can be observed, called the *visibility period.* The length and timing of the visibility period depends on the declination of the target and on whether there are any special scheduling constraints. Orbits are grouped into larger units called *visits*; a visit is a series of one or more exposures on a target, including the overheads, that will execute in one or more consecutive orbits.

Components of a Visit

The orbits in a visit generally contain the following components:

- Guide star acquisition (needed in the first orbit of a visit) or re-acquisition (needed in the subsequent orbits of a visit), to ensure that *HST* can maintain adequate pointing during each orbit. See Section 3.2 for details on guiding.

- Target acquisition. This is required if the target must be placed in an instrument aperture. Imaging observations (unless they are coronagraphic) generally do not require a target acquisition. See Section 5.2 for details on target acquisition strategies.
- Science exposures.
- Instrument overheads (e.g., the time required to set up the instrument and read out the data).
- Telescope repositioning overheads for small angle maneuvers such as pattern dithers and offsets.
- Special calibration observations, which may be required if the accuracy provided by the standard calibrations is inadequate for the goals of the project (see Section 4.3 of the Call for Proposals).

Preparing your Program

To calculate the resources required for your GO program you must take the following steps:

1. Define the observations (instrument setup, number of exposures, exposure times, etc.) you wish to execute on each target. Use the Instrument Handbooks and the Exposure Time Calculator (ETC) tools that are available on the *HST* Instruments Web page as primary resources in this stage of your proposal preparation.
2. Group your observations into separate visits following the guidelines in Section 6.2.
3. Determine the visibility period of each target in your proposal (described in Section 6.3).
4. Compute the times required for guide star acquisitions, target acquisitions, instrument overheads, and telescope repositioning overheads (described in Section 6.4 and Appendix A). *The observations for a Survey target, including overheads, must not exceed 48 minutes.* See Section 3.2.3 of the Call for Proposals
5. Lay out all the exposure and overhead times for your program into visits (described in Section 6.5) and add up the number of orbits from each visit to obtain your total orbit request. Each visit must consist of an integer number of orbits. Partial orbits are not granted.

6.1.2 Snapshot Programs

In a Phase I Snapshot proposal, the PI specifies a requested number of targets, rather than a requested number of orbits. The exposure times and overhead times for Snapshot observations are calculated in similar fashion as for GO observations. *The observations for a Snapshot target, including overheads, must not exceed 45 minutes*. See Section 3.3 of the Call for Proposals for detailed policies and procedures for Snapshot observations.

6.2 *HST* Visits

6.2.1 Defining New Visits and Optimizing Scheduling Efficiency and Flexibility

Guidelines and Rules:

The following guidelines were put in place to ensure scheduling efficiency and flexibility, and to maximize the number of scheduling opportunities during the *HST* observing cycle. We ***recommend*** that:

1. Visits should not exceed five (5) orbits. For health and safety reasons, the STIS MAMAs in particular cannot be operated in or around SAA passages, so the five orbit duration limit is strictly enforced on such visits. The ACS/SBC has the same five orbit maximum duration.
2. Exposures should be ordered and grouped such that instrument overheads occur between orbital viewing periods in multi-orbit visits.
3. Changes in *HST* pointing within an orbit should not exceed ~2 arc minutes. This can be due to an explicit change in target position (e.g. POS TARG, pattern, aperture change) or the use of a new target. *Changes larger than 2 arc minutes introduce major slews which may be accommodated but, only if science goals dictate and conditions allow it*.

A new visit is ***required*** if any of the following conditions occur:

1. A change in *HST* pointing of greater than ~1 degree.
2. The interval of time between repeated or periodic exposures creates an empty visibility period (an orbit with no exposures).
3. There is a required change in telescope orientation between observations (e.g., for NICMOS coronagraphic observations, or for STIS long-slit spectra along different position angles on the sky).

A more complete explanation of the rationale behind these guidelines and rules can be found at:

http://www.stsci.edu/hst/programs/recommendations

The practical implementation of these guidelines is dictated by the details of the telescope and instrument operating characteristics. Proposers should use the Phase I documentation and proposal tools to gain insight into how well a proposed observing scenario satisfies each of the guidelines.

In general, the rule of thumb is that "smaller is better". Thus, smaller visit durations, target separations, and instrument configurations are better, where "better" refers to telescope scheduling efficiency and flexibility. STScI will work with observers (in Phase II) to find the best observing strategy that satisfies the science goals while following these guidelines as closely as possible.

6.2.2 Instrument Specific Limitations on Visits

For all science instruments, there are instrument-specific restrictions on the definition of a visit.

ACS and WFC3: Data Volume Constraints

If ACS or WFC3 data are taken at the highest possible rate (~6 ACS/WFC or WFC3 images per nominal orbit, or ~12 images per CVZ orbit) for several consecutive orbits, it is possible to accumulate data faster than it can be transmitted to the ground. High data volume proposals will be reviewed and on some occasions, users may be requested to divide the proposal into different visits or consider using subarrays. Users can achieve higher frame rates by using subarrays, at the expense of having a smaller field-of-view; see the *ACS Instrument Handbook* or *WFC3 Instrument Handbook* for details.

FGS: Astrometry

For astrometric observations using FGS1R, each individual set (consisting of target object and reference objects) may be contained in one visit if there is no telescope motion made during the sequence.

Coronagraphy

We anticipate that most STIS or NICMOS coronagraphic observations will be single visits using the full orbit for science observations.

Proposals requesting two coronagraphic observations at different roll angles in the same orbit will have the following requirements:

- Each ACQ and its corresponding science exposures must be scheduled as a separate visit.
- Each visit must not exceed 22 minutes, including guide star acquisition, ACQ, exposure time and overhead.

• No more than two ACQs within one orbit will be allowed. The effectiveness of the roll-within-an-orbit technique has been shown to depend heavily on the attitudes of the telescope preceding the coronagraphic observation. Thus, using the technique is not a guarantee of cleaner PSF subtraction.

As an extra insurance policy, coronagraphic observers may want to consider adding an extra orbit for each new pointing. Thermal changes in the telescope are likely to be significantly smaller in the second and subsequent orbits on a target than they are in the first orbit.

Coronagraphic observations requiring particular telescope orientations (e.g., positioning a companion or disk between diffraction spikes) are time-critical and must be described in the 'Special Requirements' section of a Phase I proposal (see Section 9.3 of the Call for Proposals).

STScI will provide standard calibration reference files, flat fields, and darks, which will be available for calibration purposes. Contemporary reference files in support of coronagraphic observations are not solicited or normally approved for GO programs, but coronagraphic observers who can justify the need for contemporary calibration observations must include the additional orbit request in the Phase I proposal. Acquisition of bright targets for which an onboard ACQ with NICMOS will not be feasible requires the observer to obtain flat field observations to locate the coronagraphic hole. This implies adding one or more orbits to the total time requested. All calibration data regardless of the program are automatically made public.

STIS: CCD and MAMA Observations in the Same Visit

In general, STIS programs that contain both CCD and MAMA science observations (excluding target acquisitions) must be split into separate CCD and MAMA visits. Exceptions to this rule may be allowed if one of the following two conditions is met:

- There is less than 30 minutes of science observing time (including overheads) using the CCD at a single target position.
- The target is observed for only one orbit.

In order to preserve SAA-free orbits for MAMA observations, STIS programs that contain both CCD and MAMA science observations (excluding target acquisitions) must normally be split into separate CCD and MAMA visits.

6.3 The Visibility Period

The *visibility period* is the amount of unocculted time per orbit during which observations of a given target can be made. Table 6.1 gives the visibility period for fixed targets of given declination, for moving targets (assumed to be near the ecliptic plane), and for cases in which the special requirements **CVZ** (Section 2.2.1), **LOW** Sky (Section 8.16.12 of the Call for Proposals), and **SHADOW** (Section 8.16.12 of the Call for Proposals) are used.

The listed visibility time for the CVZ (96 minutes, i.e., the entire *HST* orbit) assumes that there are no SAA intersections in these orbits (see Section 2.2.2). This is the visibility time that you should use if you are planning CVZ observations, unless you know that you may have to observe in orbits that are SAA-impacted. In the latter case the visibility time is approximately 70 minutes per orbit. Note that CVZ orbital visibility should *not* be requested if there are special background emission or timing requirements (see Section 2.2.1).

Also included in Table 6.1 are visibilities suitable for use in Large Programs (see Section 3.2.2 of the Call for Proposals). Proposers submitting Large Programs should consult the Large Program Scheduling User Information Report which can be found on the *HST* Documents page (linked from the Cycle 18 Announcement Web page). This document contains a discussion of the issues surrounding Large Program scheduling.

Table 6.1: Orbit Visibility in Three-gyro Mode.

Target	|Declination| (degrees)	Visibility [min.]	LARGE visibility [min.]	LOW visibility [min.]	SHADOW visibility [min.]
Moving	object near ecliptic plane	54	50	47	25
Fixed	0–30°	54	50	47	25
Fixed	30-40°	55	50	48	25
Fixed	40-50°	57	50	48	25
Fixed	50-60°	58	50	45	25
Fixed	60–70°	59	50	45	25
Fixed	70-80°	60	51	43	25
Fixed	80-90°	61	52	42	25
Any	Any CVZ declination	96	96	incompatible	incompatible

Visibility Period for Pure Parallel Observations

If you are proposing for Pure Parallel observations (see Section 4.2.2 of the Call for Proposals), then you may not know the prime target declinations. You should then use one of the following two options when planning your observations:

- Use the minimum allowed visibility period given your target selection criteria; e.g., if your requirement calls for fields around M31 (at a declination of 50 degrees), then use 57 minutes.
- Map out the exposures (plus overheads) you wish to obtain in an orbit for any legal visibility period (54–61 minutes). If you select this method, note that longer total exposure times typically have fewer opportunities to schedule.

6.4 Acquisition Times and Instrument Overheads

You cannot use the entire target visibility time for actual science exposures, because of the required times for guide star acquisition, target acquisition, and SI overheads. The following subsections discuss the amounts of time that should be budgeted for these items; they are conservative approximations suitable for use in a Phase I proposal and may differ slightly from the numbers in the Instrument Handbooks.

6.4.1 Guide Star Acquisition Times

A normal guide star acquisition, required in the first orbit of every visit, takes 6 minutes. At the beginning of subsequent orbits in a multi-orbit visit, the required guide star *re*-acquisition takes 4 minutes. For CVZ observations guide star re-acquisitions are not required but, if an observation extends into SAA-impacted orbits (see Section 2.2.2), then guide star re-acquisitions will be necessary for those orbits.

Table 6.2: Guide Star Acquisition Times

Type of Acquisition	Time [min.]	Use
Guide star acquisition	6	First orbit of every visit. Applies also to Snapshot observations.
Guide star re-acquisition	4	All orbits of a multi-orbit visit, except the first orbit. May not be needed for CVZ observations (see text).

6.4.2 Target Acquisition Times

A target acquisition may be required after the guide star acquisition, depending on the SI used and pointing requirements. See Section 5.2 for a basic overview of target acquisitions. Consult the *HST* Instrument Handbooks to determine whether a target acquisition is required for your particular observations, and which acquisition type is most appropriate. Then use Table 6.3 to determine the time that you need to budget for this.

The most common use of target acquisition is for COS and STIS spectroscopy. A number of target acquisition options are provided for each instrument. In some cases an additional set of peak-up observations can follow the initial instrument acquisition.

Most **normal imaging** observations with ACS, NICMOS, STIS and WFC3 do not require a target acquisition (assuming that the coordinates delivered by the observer in Phase II have sufficient accuracy of 1"-2"). However, for **coronagraphic imaging** with NICMOS/NIC2, or STIS, you will need to perform a target acquisition to place the target behind the coronagraphic hole or feature. For STIS, the same ACQ and ACQ/PEAK strategies are available as for spectroscopy. For COS, the same acquisition strategies are available as for spectroscopy. For NICMOS/NIC2, modes called ACQ are available. Note that the acquisition algorithms work differently for the different instruments, even if the modes have the same names.

FGS observations use a so-called spiral search location sequence for target acquisitions. This is part of a science observation, and the time required for the acquisition is considered to be part of the overhead associated with the science observation (see Table 6.6).

In exceptional cases you may require a **real-time interaction** with the telescope to perform a target acquisition (see Section 5.2.2). You will then first obtain an image, which you should treat as a normal science exposure. Then add 30 minutes for the real-time contact (which may overlap with the occultation interval at the end of an orbit).

Table 6.3: Target Acquisition Times

SI	Type of Acquisition	Time [min.]	Notes
COS	ACQ/IMAGE	3	Typical acquisition in NUV integrated light (recommended). Total time required is 2 min. + (2 x exposure time)
COS	ACQ/SEARCH, ACQ/PEAKXD, ACQ/PEAKD	15	Typical p recision acquisition in dispersed light (for targets with either NUV or FUV). Total time required for full sequence is ~10 min. plus (15 x exposure time)
NICMOS	ACQ	3	Used to position a target behind the NIC2 coronagraphic hole.
STIS	ACQ	6	Used for STIS spectroscopy or coronagraphy. For faint targets (V > 20), add 4 times the acquisition exposure time determined by the Target Acquisition ETC.
STIS	ACQ/PEAK	6	Used for STIS spectroscopic observations in apertures <= 0.1" in size, or for any STIS spectroscopic observation that requires the highest possible absolution precision in the zeropoint of the wavelength scale.This type of target acquisition always follows an ACQ. For faint targets (V > 20),add 4 times the acquisition exposure time determined by the Target Acquisition ETC.
Any	Interactive	30	Used for real-time interactions with the telescope in very exceptional circumstances.

Generally, a target acquisition does not need to be repeated for separate orbits of a multi-orbit visit. However, we recommend that observers planning multi-orbit observations in 0.1" or smaller STIS slits insert a target peakup maneuver every 4 orbits (see Section 3.2.1).

A target acquisition, if necessary, usually should be inserted in each visit. However, programs with multiple visits to the same target within a six-week period (start to finish) may be able to use the **Reuse Target Offset** function (see Section 5.2.2). If reuse target offset is appropriate for your program, then you should include the full target acquisition sequence only in the initial visit; the subsequent visits will not need a full target acquisition. However, they will require a **Small Angle Maneuver** (SAM) (see Section 6.4.4) for the offset maneuver, and they usually require the final peakup stage used in the original acquisition. Please contact the STScI Help Desk (see Section 1.4) if you feel your program can benefit from this capability.

6.4.3 Instrument Overhead Times

There are a variety of instrument overheads associated with science exposures. Tables 6.4 to 6.11 summarize for each instrument how much time you need to budget for these overheads, depending on the observing strategy.

For several years, many observers have been using *dithering*, or small spatial displacements, to allow for better removal of detector defects and the reconstruction of sub-pixel resolution. In general, *undithered* observations with the ACS CCD and WFC3 detectors will not be approved without strong justification that such is *required* for the scientific objectives (see Section 5.2.)

ACS

ACS overheads are listed in Tables 6.4 and 6.5.

The overhead per exposure is shorter if the exposure is the same as the previous exposure (i.e. the exposures use the same aperture and spectral element, but not necessarily the same exposure times). If you are unsure whether the shorter overhead time is appropriate, then use the longer overhead time (to avoid a possible orbit allocation shortfall later).

Table 6.4: ACS Exposure Overheads

SI Mode	Time [min.] WFC	Time [min.] SBC	Notes
IMAGING/ SPECTROSCOPIC	4.0	1.7	A single exposure or the first exposure in a series of identical exposures.
IMAGING/ SPECTROSCOPIC	2.5	0.9	Subsequent exposures in an identical series of exposures.
IMAGING/ SPECTROSCOPIC	5.7	0	Additional overhead for subsequent exposures (except the last) in an identical series of exposures if the exposure time is less than 6 minutes.
SPECTROSCOPIC	N/A	N/A	Automatically executed (if AUTOIMAGE =YES) imaging exposure for prism spectroscopy (provides the image to co-locate the targets and their spectra; see the *ACS Instrument Handbook* for details).
SPECTROSCOPIC	7	N/A	Automatically executed (if AUTOIMAGE =YES) imaging exposure for grism spectroscopy (provides the image to co-locate the targets and their spectra; see the *ACS Instrument Handbook* for details).

Note that if AUTOIMAGE=NO is invoked and a different direct image is specified for the WFC spectroscopic calibration, and in all cases for the SBC calibration (for which there is no Autoimage due to the safety issue), these direct images must be included explicitly in the Observing Summary and the observing time (orbit) request of the Phase I proposal.

COS

Details on COS overheads are provided in the *COS Instrument Handbook* and incorporated into the COS ETCs and APT. The following are typical values.

Table 6.5: COS Exposure Overheads

Mode	Time [min.]	Notes
IMAGING/SPECTROSCOPY	5	A single exposure or the first exposure in a series of identical exposures
IMAGING/SPECTROSCOPY	2	subsequent exposures in a series of identical exposures

FGS

FGS overheads are listed in Tables 6.6 and 6.7.

The total TRANS mode overhead consists of an acquisition overhead plus an overhead per scan. Hence, the total overhead depends on the number of scans obtained during a target visibility period. In Table 6.8 we list the recommended number of scans as a function of target magnitude. The recommended *exposure* time is 40 seconds per scan (excluding overheads).

Table 6.6: FGS Exposure Overheads

SI Mode	Time [min.]	Notes
POS	1	if target magnitude $V < 14$
POS	2	if target magnitude $14 < V < 15$
POS	3	if target magnitude $15 < V < 16$
POS	4	if target magnitude $16 < V < 16.5$
POS	8	if target magnitude $V > 16.5$
TRANS	1	target acquisition (independent of target magnitude)
TRANS	0.2	overhead per scan (independent of target magnitude)

Table 6.7: FGS Miscellaneous Overheads

Type	Time [min.]
Instrument Setup, per orbit	4
Instrument Shutdown, per orbit	3

Table 6.8: Recommended number of FGS TRANS mode scans

V-magnitude	# scans
8-12	10
13-14	20
15	30
16	60

NICMOS

A large number of different overheads exist for NICMOS observations, as listed in Tables 6.9 and 6.10, and discussed in detail (with examples) in Chapter 10 of the *NICMOS Instrument Handbook*.

The overhead for the MULTIACCUM mode (the readout mode that proposers are encouraged to use whenever possible) is fixed. The overhead on the ACCUM mode is a function of the number of reads, NREAD, obtained at the beginning (and at the end) of an exposure. The range of allowed NREADs is 1 (default) to 25.

Table 6.9: NICMOS Exposure Overheads

SI Mode	Time	Notes
IMAGING/ SPECTROSCOPIC	4 sec	MULTIACCUM exposures
IMAGING/ SPECTROSCOPIC	7 + (NREAD x 0.6) sec	ACCUM exposures; NREAD=1-25

Table 6.10: NICMOS Miscellaneous Overheads

Type	Time [min.]
Instrument set-up at the beginning of an orbit	0.3
Filter change in the same camera	0.3
Overhead for switching from NIC1 to NIC2, or vice versa, in an orbit	1.4
Overhead for switching from NIC1 to NIC3 or vice versa, in an orbit	9.7
Overhead for switching from NIC2 to NIC3 or vice versa, in an orbit	4.8

STIS

STIS overheads are listed in Table 6.11. The overhead per exposure is shorter if the exposure is the same as the previous exposure ('no change'); this means that the exposures use the same aperture, grating and central wavelength, but the exposure times need not be the same. If you are unsure whether the shorter overhead time is appropriate, then use the longer overhead time.

Table 6.11: STIS Exposure Overheads

Config/Mode	Time [min.]	Notes
CCD IMAGING	5	Overhead per exposure.
CCD SPECTROSCOPIC	5	Overhead per exposure.
CCD SPECTROSCOPIC	2 (4)[1]	Overhead for a series of identical exposures extending more than ~40 min
CCD IMAGING/SPECTROSCOPIC	1	Overhead per exposure, if no change from the previous exposure.
MAMA IMAGING (FUV or NUV)	5	Overhead per exposure.
MAMA IMAGING (FUV or NUV)	1	Overhead per exposure, if no change from the previous exposure.
MAMA SPECTROSCOPIC (FUV or NUV)	8	Overhead per exposure.
MAMA SPECTROSCOPIC (FUV or NUV)	4 (6)[1]	Overhead for a series of identical exposures extending more than ~40 min
MAMA SPECTROSCOPIC (FUV or NUV)	1	Overhead per exposure, if no change from the previous exposure.

1. For the medium resolution modes G140M, G230M, and G230MB, there are some wavelength-slit combinations that require longer autowavecal exposure times. For each set of exposures totaling more than 2300 seconds at the same grating position for mode G230MB, an overhead of 4 minutes should be budgeted. For each set of exposures totaling more than 2300 seconds at the same grating position for modes G140M and G230M, an overhead of 6 minutes should be budgeted.

WFC3

Table 6.12: WFC3 Instrument Overhead Times

Action	Time [min.]
Reconfiguration between UVIS & IR channels during a single orbit	1.0
Change quad filter (UVIS only)	1.0
UVIS ACCUM Mode	
Single exposure or first exposure in a set of identical exposures (e.g., the first sub-exposure of a CR-SPLIT set)	2.6
Subsequent exposures in set of identical exposures (e.g., subsequent exposures in a CR-SPLIT set), per exposure	2.1
Buffer dump if exposure is not last one in an orbit, or if next exposure is less than 339 seconds	5.8
IR MULTIACCUM Mode	
Each exposure	1.0
Buffer dump if 16-read exposure is not last one in an orbit, or if next exposure is less than 346 seconds	5.8

6.4.4 Telescope Repositioning Overhead Times

Small Angle Maneuvers (SAMs) are changes in telescope pointing of less than 2 arcmin. Table 6.13 lists the overhead times for SAMs.

Table 6.13: Small Angle Maneuver Time

Step-size	SAM time [seconds]
0" < step-size < 1.25"	20
1.25" < step-size < 10"	30
10" < step-size < 28"	40
28" < step-size <60"	50
60" < step-size < 2'	65

A “Reuse Target Offset” visit (see Section 5.2.2 and Section 6.4.2) will require a SAM to be scheduled at the start of the first orbit. To allow for the offset adjustment, the SAM should be assumed to have a duration of 30 seconds.

Patterns (see Section 5.4) perform a series of SAMs. The timing and subsequent overheads depend on the size of the pattern. However, a simple estimate for the overhead time associated with a pattern is obtained by multiplying the number of points minus 1 times the overhead time for a single SAM (see Table 6.13) whose size matches the pattern spacing.

6.5 Constructing Your Program

Your final step is to fit all science exposures and overheads into the visibility period of each orbit for all your visits. The better you can pack your orbits, the more efficient your proposal will be. For particularly complex programs, the APT phase II orbit planner can be used for assessing the orbit layout. Please contact help@stsci.edu if you need assistance.

When placing the observations into orbits and visits, note that you cannot pause exposures across orbits. This means that if you have 20 minutes left in an orbit, you can insert only an exposure that takes 20 minutes or less (including overhead). If you wish to obtain a 30 minute exposure, then you can either put it all into the next orbit, or you can specify, for example, a 20 minute exposure at the end of the first orbit, and a second 10 minute exposure in the next orbit.

Table 6.14 shows, as an example, the layout of a visit with 2 orbits of spectroscopic observations that require a target acquisition, but no SAMs and no special calibration observations. For simplicity, overheads are shown to occur after each exposure; in reality some overheads occur before an exposure (e.g., a filter change) while others appear afterwards (e.g., read-out time).

Table 6.14: Example Visit

Orbit 1	Guide Star Acquisition	Target Acq.	Overhead	Science Exp.	Overhead	Earth Occult.
Orbit 2	Guide Star Re-acquisition	Science Exp.	Overhead	Science Exp.	Overhead	Earth Occult.

More detailed examples for each of the SIs are given in Appendix A. Those examples are for common, simple uses of the instruments. For examples of more complicated uses and observing strategies, please consult the *HST* Instrument Handbooks (see Section 1.3).

Coordinated Parallel Observations

If you have a program with coordinated parallel observations (see Section 4.2.1 of the Call for Proposals), then it should be fairly straightforward to lay out the parallel observations into orbits and visits. The primary observations determine the orbit and visit structure, and the coordinated parallels should conform to the visit structure of the primary observations.

CHAPTER 7:

Data Processing and the *HST* Data Archive

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7.1 Routine Science Data Processing

Science data obtained with *HST* are sent to the TDRSS satellite system, from there to the TDRSS ground station at White Sands, New Mexico, then to the Sensor Data Processing Facility at Goddard Space Flight Center in Greenbelt, Maryland, and then finally to STScI. At STScI the production pipeline provides standard processing for data editing, calibration, and product generation. These functions, performed automatically, include the following:

- Reformatting and editing of data from spacecraft packet format to images and spectra.
- Performing standard calibrations (flat fields, wavelength calibrations, background subtraction, etc.) with currently available calibration files.
- Producing standard data output products (FITS files of raw and calibrated images, OMS [jitter and performance flags] files, and so on).

The standard calibrations performed on *HST* data, and the resulting output data products, are described in detail in the *HST Data Handbook*. Note that the Archive no longer saves the initial versions of the calibrated data (since 2000), nor the initial version of the uncalibrated FITS data (since 2005). Rather, when you request data from the active instruments, the production pipeline is run on-the-fly starting from the spacecraft packet format files, as described in Section 7.2.1

7.1.1 Space Telescope Science Data Analysis System (STSDAS)

STScI maintains a set of tools and support software used to calibrate and analyze *HST* data. One such tool is the Space Telescope Science Data Analysis System (STSDAS) and its accompanying package, TABLES. STSDAS provides access to all the existing calibration pipeline programs used by STScI to process all *HST* data so that *HST* observers can recalibrate their data, examine intermediate calibration steps, and re-run the pipeline using different calibration switch settings and reference data as appropriate. STSDAS also has various applications for the analysis of *HST* data as well as various utilities for manipulating and plotting data. The TABLES package facilitates the manipulation of FITS table data. STSDAS and TABLES are layered onto the Image Reduction and Analysis Facility (IRAF) software from the National Optical Astronomy Observatories (NOAO). Both packages run from within IRAF and are supported on a variety of platforms, although not all of the platforms that IRAF supports.

Much of the newer calibration and analysis software is written in Python, does not require IRAF, and is available as part of STScI Python library. PyRAF is an alternate, Python-based command line environment for IRAF that enables the new Python-based software to be used along with IRAF tasks using IRAF command line syntax. Stsci_python includes PyFITS, a module that provides Python programs the ability to read and write FITS files. The new Python environment allows users to manipulate and display data in a way not possible with IRAF that is more akin to how data can be manipulated and displayed by IDL (Interactive Data Language). The STScI Python environment described above is contained within the stsci_python package.

Detailed information on STSDAS, TABLES, PyRAF, PyFITS and other Python-based software, including the actual software, is available from the STScI Software Web page. Information about IRAF is available from the IRAF Web page.

7.2 The *HST* Data Archive

All science and calibration data, along with a large fraction of the engineering data, are placed in the *HST* Data Archive. Science data become immediately available to a program's Principal Investigator (PI) and those designated by the PI. These data may be retrieved after the PI has registered as an archive user and are normally proprietary for a period of one year (see Section 5.1 of the Call for Proposals for information on data rights).

On average, the science data from *HST* flow through the production pipeline and into the archive within one day after observation on the telescope. Some data may take as long as three to five days. The observer is notified by e-mail when the first datasets reach the archive and is provided with Web tools to track a visit's completeness and to retrieve the data generated by the pipeline. The time required for retrieving data from the archive is typically a few hours. However, occasional software or system failures may lengthen the processing and retrieval times.

If you have strict scientific requirements for data receipt within days after execution, such as to provide pointing corrections for tightly scheduled visits, there are resource-intensive methods to expedite delivery of data. If you have such requirements, they must be stated in your proposal so that the resource needs can be determined and reviewed (see Section 9.3 of the Call for Proposals).

As of October 2009, *HST* Data Archive contained over 903,000 individual observations. These observations, along with engineering and other supporting information, comprise over 42 Terabytes of data. About 180 new observations are archived every day. The heart of the archive is the Data Archive and the Distribution Service (DADS), hard disk arrays where the data are stored, a collection of Ultra Density Optical disks for off-site back-up storage, databases that comprise the archive catalog, and the hardware and software that support the ingest and distribution of *HST* data.

7.2.1 Web Access to the *HST* Data Archive

Most of the data in the *HST* Data Archive are public and may be retrieved by any user. The archive can be accessed through the MAST Web page. The Web interface can do simple searches by object name or location or by lists of names or locations, and it can retrieve data and calibration files.The archive is developing a new Web based Starview interface to replace the Starview Java application. The new Starview will support much of the same functionality of the old Starview, permitting users access to instrument specific database tables. Users will be able to choose the meta data of interest to construct their own, personalized queries and output. At the time the document is being prepared, the application is getting ready to enter beta testing. Check the *HST* Data Archive "News Feed" at http://archive.stsci.edu/index.html for the announcement.

The MAST Web site allows you to preview most of the publicly available images and spectra. The interface also offers integrated access to the Digitized Sky Survey (DSS) and allows the user to access the Set of Identifications, Measurements and Bibliography for Astronomical Data (SIMBAD) or NASA/IPAC Extragalactic Database (NED) to look up the coordinates of an object by name.

All ACS, COS and WFC3 data requested from the archive, as well as all new NICMOS and STIS data acquired after SM4, will be reprocessed in the pipeline at the time of the request. On-The-Fly Reprocessing (OTFR) takes the science data in spacecraft package format and generates calibrated files. On-The-Fly Reprocessing prepares a new FITS file with each request, which allows a clean integration of new headers with updated keywords that are fully compatible with the latest version of the pipeline and calibration software. Data from the legacy instruments and data from the NICMOS and

STIS acquired before SM4 were reprocessed with optimized software and reference files, and are available from the static archive. DADS allows users to filter their retrievals to obtain only the files they need (as well as allowing secure ftp retrievals for most users and retrieval of compressed data).

While STIS was inoperable after its failure in August 2004, all pre-failure archival STIS data were recalibrated, and starting in Summer of 2007, these data were served from a static archive rather than being reprocessed through OTFR, allowing for significantly faster data retrievals. A description of the improvements made as part of this recalibration are available at the STIS Closeout Web page. Concurrently with SM4, OTFR was re-enabled for all post-SM4 STIS data. Archive requests for the older pre-SM4 STIS data continue to be filled using the static archive.

Similarly, while NICMOS was inoperable after the SI C&DH failure in September 2008, all pre-SM4 archival NICMOS data were recalibrated, and these data are served from a static archive rather than being reprocessed through OTFR, allowing for significantly faster data retrievals. OTFR is enabled for all post-SM4 NICMOS data.

Finally, all observations from the WFPC2 have been recalibrated and are available in the static archive. A description of the improvements made as part of this recalibration are available at the WFPC2 Reprocessing Web page:

(http://www.stsci.edu/hst/wfpc2/wfpc2_reproc.html).

STScI maintains an "Archive Hotseat" to which all archive-related questions, problems, or comments should be referred. The Archive Hotseat can be reached by email at archive@stsci.edu or by phone at 410-338-4547.

7.3 Hubble Legacy Archive (HLA)

The Hubble Legacy Archive (HLA) is a project designed to enhance science from the Hubble Space Telescope by augmenting the *HST* Data Archive and by providing advanced browsing capabilities. It is a joint project of the Space Telescope Science Institute, the European Coordinating Facility, and the Canadian Astronomy Data Centre. The primary enhancements are:

- All advanced data products are immediately available online for viewing searching, and downloading,
- a footprint service makes it easier to browse and download images,
- combined images and prototype mosaics are available,
- for many images, the absolute astrometry has been improved from 1 - 2 arcsec to ~0.3 arcsec,
- source lists are available for ACS and WFPC2 observations,
- NICMOS and ACS grism extractions have been produced by ST-ECF,
- an interface is provided to many user-provided High Level Science Products.

At this writing, the HLA has completed its third major Data Release, including enhanced data products for almost all science data for ACS and WFPC2 through mid-2008, and about a third of NICMOS data (all the pre-NCS data), as well as source lists for ACS and WFPC2. A small number of prototype multi-visit ACS mosaics are also available. The footprint service shows the outline of data from all instruments, including those that are still proprietary, and an interface to the main *HST* Data Archive is provided to access proprietary and recent data for which enhanced HLA products are not yet available. Some of the more general goals of the HLA are to make *HST* data VO (Virtual Observatory) compatible, to move toward a sky atlas user view rather than a collection of datasets, and to develop an "all-*HST*-sky" source list.

The HLA can be accessed at http://hla.stsci.edu.

APPENDIX A:

Orbit Calculation Examples

In this appendix...

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A.1 ACS

Suppose that you wish to use the ACS to observe a target at a declination of +35 degrees, so that there are 55 minutes of visibility time per orbit (see Table 6.1). Your desired exposures are listed in table A.1, and the associated overheads are listed in table A.2. In table A.3 you can see how the observations fit into a total of 2 orbits.

Table A.1: ACS Example: Planned Exposures

Config	Mode	Spectral Element	Number of Exp	Time per Exp [min.]	Notes
ACS/WFC	IMAGING	F606W	4	8.75	Pattern (see section 5.4) with an offset of 25" between positions

Table A.2: ACS Example: Incurred Overheads

Overhead	Overhead Time [min.]	Notes	see Table
Guide star acquisition	6	First orbit in new visit	6.2
Guide star re-acquisition	5	Per orbit after first orbit	6.2
WFC exposure (first)	4	First exposure in a series of identical exposures	6.4
WFC exposure (not first)	2.5	Per exposure after the first exposure in a series	6.4
SAM of 25"	0.67	Small Angle Maneuver between positions in the pattern	6.14

Table A.3: ACS Example: Orbit Planning

Activity	Duration [min.]	Elapsed Time [min.]
Orbit 1		
Guide star acquisition	6	6
WFC/F606W Exp Time	4x8.75	41
WFC/F606W Overhead	4+(3x2.5)+(3x0.67)	54.5
Unused time	0.5	55
Orbit 2		
Guide star re-acquisition	5	5
HRC/F814W Overhead	2.5+1	19.5
HRC/F606W Exp Time	2x7	33.5
HRC/F606W Overhead	2.5+1	37
HRC/F435W Exp Time	2x7	51
HRC/F435W Overhead	2.5+1	54.5
Unused time	0.5	55

A.2 COS

Here we illustrate two examples of COS usage. These are taken from the COS Instrument Handbook, which provides additional information and details.

In the first example, we use the NUV channel of COS to first acquire an object in imaging mode, and then to obtain a TIME-TAG spectrum with two exposures using different gratings. Let's assume the target is at declination -10 degrees, so that there are 54 minutes of visibility time per orbit (see Table 6.1).

Table A.4: COS Example 1: Planned Exposures.

Config	Mode	Spectral Element	Number of Exp	Time per Exp [sec.]	Notes
COS/NUV	ACQ/IMAGE	MIRRORA	1	20	target acquisition
COS/NUV	TIME-TAG	G185M	1	1200[1]	central wavelength 1850 A
COS/NUV	TIME-TAG	G225M	1	600[1]	central wavelength 2250 A

Table A.5: COS Example 1: Incurred Overheads

Overhead	Overhead Time [min.]	Notes	see Table
Guide star acquisition	6	first orbit in new visit	6.2
ACQ/IMAGE	3	target acquisition	6.3
NUV Spectroscopy	5	single spectroscopic exposure	6.6

[1] The exposure times were arbitrarily taken to be 1200 and 600 seconds for two exposures; these can be adjusted to fill a visibility period. Longer exposures into additional orbits require 5 minutes for the guide star re-acq but no additional overheads if the grating or wavelength is not changed.

Table A.6: COS Example 1: Orbit Planning

Activity	Duration [min.]	Elapsed Time [min.]
Orbit 1		
Guide star acquisition	6	6
ACQ/IMAGE	3	9
G185M Overhead	5	13
G185M Exp time	20	34
G225M Overhead	5	39
G225M Exp time	10	49
Unused	2	54

In the second example, we use the NUV channel of COS to acquire an object in imaging mode, and then we use the FUV channel to obtain a TIME-TAG spectrum with two exposures using the same setting (same grating and central wavelength). The same target of example 1 is assumed, with 54 minutes of visibility time per orbit.

Table A.7: COS Example 2: Planned Exposures.

Config	Mode	Spectral Element	Number of Exp	Time per Exp [sec.]	Notes
COS/NUV	ACQ/IMAGE	MIRRORA	1	30	target acquisition
COS/FUV	TIME-TAG	G160M	1	2100	central wavelength 1600 A
COS/FUV	TIME-TAG	G160M	1	2700	central wavelength 1600 A

Table A.8: COS Example 2: Incurred Overheads

Overhead	Overhead Time [min.]	Notes	see Table
Guide star acquisition	6	first orbit in new visit	6.2
Guide star re-acquisition	5	per orbit after first orbit	6.2
ACQ/IMAGE	3	target acquisition	6.3
FUV spectroscopy	5	first spectroscopic exposure in a series of identical exposures	6.6
FUV spectroscopy	2	subsequent spectroscopic exposure in a series of identical exposures	6.6

Table A.9: COS Example 2: Orbit Planning

Activity	Duration [min.]	Elapsed Time [min.]
Orbit 1		
Guide star acquisition	6	6
ACQ/IMAGE	3	9
G160M Overhead	5	14
G160M Exp time	35	49
Unused	5	54
Orbit 2		
Guide star re-acquisition	5	5
G160M Overhead	2	7
G160M Exp time	45	52
Unused	2	54

A.3 FGS

Suppose that you wish to use the FGS to observe a binary star named Binary01, as well as five reference stars ref1,......,ref5. All stars are in the same FGS field of view, and can therefore be observed in one and the same visit (see Section 6.2.2). Stars ref4 and ref5 have magnitude V=14.6, and all the other targets have 13.0<V<14.0. The targets have a declination of +42 degrees, so that there are 57 minutes of visibility time per orbit (see Table 6.1). To enable the removal of drift and jitter in the post observation analysis of the data, the binary is observed in POS mode several times (twice in our example) and the reference stars are each observed twice. Your desired exposures are listed in table A.10, and the associated overheads are listed in table A.11. In table A.12 you can see how this fits into a total of 1 orbit.

Table A.10: FGS Example: Planned Exposures

Config	Mode	Spectral Element	Number of Exp	Time per Exp [min.]	Notes
FGS	POS	F583W	8	0.6	2 exposures of target Binary01, and 2 exposures for each of the targets ref1, ref2, and ref3
FGS	POS	F583W	4	1.1	2 exposures for each of the targets ref4 and ref5
FGS	TRANS	F583W	1	13.4	20 scans of 40 sec each (see table 6.9) for Binary01

Table A.11: FGS Example: Incurred Overheads

Overhead	Overhead Time [min.]	Notes	see Table
Guide star acquisition	6	First orbit in new visit	6.2
POS	1	per exposure, V<14	6.7
POS	2	per exposure, 14<V<15	6.7
TRANS	1	per target	6.7
TRANS	0.2	per scan	6.7
Instrument Setup	4	once every orbit	6.8
Instrument Shutdown	3	once every orbit	6.8

Table A.12: FGS Example: Orbit Planning

Activity	Duration [min.]	Elapsed Time [min.]
Orbit 1		
Guide star acquisition	6	6
Instrument Setup	4	10
Binary01/POS mode Exp Time	0.6	10.6
Binary01/POS mode Overhead	1	11.6
ref1/POS mode Exp Time	0.6	12.2
ref1/POS mode Overhead	1	13.2
ref2/POS mode Exp Time	0.6	13.8
ref2/POS mode Overhead	1	14.8
ref3/POS mode Exp Time	0.6	15.4
ref3/POS mode Overhead	1	16.4
ref4/POS mode Exp Time	1.1	17.5
ref4/POS mode Overhead	2	19.5
ref5/POS mode Exp Time	1.1	20.6
ref5/POS mode Overhead	2	22.6
Binary01/POS mode Exp Time	0.6	23.2
Binary01/POS mode Overhead	1	24.2
ref1/POS mode Exp Time	0.6	24.8
ref1/POS mode Overhead	1	25.8
ref2/POS mode Exp Time	0.6	26.4
ref2/POS mode Overhead	1	27.4
ref3/POS mode Exp Time	0.6	28
ref3/POS mode Overhead	1	29
ref4/POS mode Exp Time	1.1	30.1
ref4/POS mode Overhead	2	32.1
ref5/POS mode Exp Time	1.1	33.2
ref5/POS mode Overhead	2	35.2
Binary01/TRANS mode Exp Time	13.4	48.6
Binary01/TRANS mode Overhead	1+(20x0.2)	53.6
Instrument Shutdown	3	56.6
Unused	0.4	57.0

A.4 NICMOS

Suppose that you wish to use the NICMOS to observe a target at a declination of −70 degrees, so that there are 59 minutes of visibility time per orbit (see Table 6.1). Your desired exposures are listed in table A.13, and the associated overheads are listed in table A.14. In table A.15 you can see how the observations fit into a total of 1 orbit.

Table A.13: NICMOS Example: Planned Exposures

Config	Mode	Spectral Element	Number of Exp	Time per Exp [min.]	Notes
NIC2	IMAGING	F110W	4	2.7	Pattern (see Section 5.4) of MULTIACCUM exposures with an offset of 1" between dither positions
NIC2	IMAGING	F160W	4	4.5	Pattern (see Section 5.4) of MULTIACCUM exposures with an offset of 1" between dither positions
NIC2	IMAGING	F222M	4	4.5	Pattern (see Section 5.4) of MULTIACCUM exposures with an offset of 1" between dither positions

Table A.14: NICMOS Example: Incurred Overheads

Overhead	Overhead Time [min.]	Notes	see Table
Guide star acquisition	6	First orbit in new visit	6.2
MULTIACCUM exposure	0.07		6.10
Instrument Setup	0.3	Beginning of each orbit	6.11
Filter change	0.3		6.11
SAM of 1"	0.33	Small Angle Maneuver between positions in the pattern	6.14

Table A.15: NICMOS Example: Orbit Planning

Activity	Duration [min.]	Elapsed Time [min.]
Orbit 1		
Guide star acquisition	6	6
Instrument Setup	0.3	6.3
F110W Exp Time	2.7	9.0
F160W Exp Time	4.5	13.5
F222M Exp Time	4.5	18.0
Overhead	(3x0.07) + (2x0.3) + (1x0.33)	19.2
F110W Exp Time	2.7	21.9
F160W Exp Time	4.5	26.4
F222M Exp Time	4.5	30.9
Overhead	(3x0.07) + (3x0.3) + (1x0.33)	32.1
F110W Exp Time	2.7	34.8
F160W Exp Time	4.5	39.3
F222M Exp Time	4.5	43.8
Overhead	(3x0.07) + (3x0.3) + (1x0.33)	45.0
F110W Exp Time	2.7	47.7
F160W Exp Time	4.5	52.2
F222M Exp Time	4.5	56.7
Overhead	(3x0.07) + (3x0.3) + (1x0.33)	57.9
Unused	1.1	59

A.5 STIS

Suppose that you wish to use STIS to observe a target at a declination of +15 degrees, so that there are 54 minutes of visibility time per orbit (see Table 6.1). Your desired exposures are listed in table A.16, and the associated overheads are listed in table A.17. In table A.18 you can see how this fits into a total of 2 orbits.

Table A.16: STIS Example: Planned Exposures

Config	Mode	Spectral Element	Number of Exp	Time per Exp [min.]	Notes
STIS/CCD	ACQ			0.1	target acquisition
STIS/CCD	ACQ/PEAK			1	peakup acquisition (necessary because of use of 0.1" wide slit for subsequent spectra)
STIS/CCD	IMAGING	F28X50OII	2	2	
STIS/NUV	IMAGING	F25QTZ	1	21	
STIS/NUV	SPECTROSCOPIC	G230L	1	13	with 52X0.1 slit
STIS/FUV	SPECTROSCOPIC	G140L	1	20	with 52X0.1 slit

Table A.17: STIS Example: Incurred Overheads[1]

Overhead	Overhead Time [min.]	Notes	see Table
Guide star acquisition	6	first orbit in new visit	6.2
Guide star re-acquisition	5	per orbit after first orbit	6.2
ACQ	6	target acquisition	6.3
ACQ/PEAK	6	peakup target acquisition	6.3
CCD imaging (first)	5	first exposure in a series of identical exposures	6.12
CCD imaging (not first)	1	per exposure after the first exposure in a series	6.12
MAMA imaging	5	first exposure	6.12
MAMA spectroscopy	8	but only 1 min. if no change from first exposure. Add 4 min. (6 min. for modes G140M, G230M) for each exposure time interval that exceeds 2300 sec at the same grating position.	6.12

1.These overheads are for budgeting purposes. The actual overhead incurred depends upon the particular spectral element selected since the overhead to move the grating is position dependent and the time for an auto-wavecal is mode dependent. Additional efficiencies, such as executing auto-wavecals during guide star re-acquisitions or occultation, that may be realized from fine tuning of the actual exposures (but cannot be assumed a priori) are not included.

Table A.18: STIS Example: Orbit Planning

Activity	Duration [min.]	Elapsed Time [min.]
Orbit 1		
Guide star acquisition	6	6
ACQ	6	12
ACQ/PEAK	6	18
F28X50OII Exp Time	2x2	22
F28X50OII Overhead	5+1	28
F25QTZ Exp Time	21	49
F25QTZ Overhead	5	54
Unused	0	54
Orbit 2		
Guide star re-acquisition	5	5
G230L Exp Time	13	18
G230L Overhead	8	26
G140L Exp Time	20	46
G140L Overhead	8	54
Unused	0	54

A.6 WFC3

A.6.1 Example 1: IR, 1 orbit, 2 filters

The first example demonstrates the orbit calculation for a simple IR observation. We want to obtain images of a target in two filters, F110W and F160W. Suppose that the ETC has shown that the exposure times adequate for our scientific goals are 10 minutes in F110W and 20 minutes in F160W. These times can be achieved with the up-the-ramp MULTIACCUM sequences SPARS50 (11.7 min) and SPARS100 (23.4 min), respectively. From the orbit visibility table (see Chapter 6), suppose that we find that at the target declination the target visibility time is 54 minutes. The orbit calculation goes like this:

Table A.19: Orbit Calculation for WFC3 Example 1

Action	Time (minutes)	Explanation
Guide-star acquisition	6.0	Needed at start of observation of new target
IR overheads for 2 exposures	2 × 1.0 = 2.0	Includes filter changes, camera set-ups, and readouts
Science exposure in F110W	11.7	
Science exposure in F160W	23.4	
Total time used	43.1	

The total time used in the orbit shows that our target can indeed be imaged in the selected filters within one orbit. Furthermore, the first exposure can be dumped from the buffer during the second exposure. The ~9 minutes of unused time could be used for an additional exposure, during which the second exposure would be dumped.

A.6.2 Example 2: UVIS, Dithering, 2 Orbits, 1 Filter

This example illustrates the orbit calculation for a UVIS observation with a WFC3 UVIS box dithering pattern, which implements imaging at four pointings. The goal of the observation is to obtain a dithered image of a field in such a way that would allow us to bridge the ~1 arcsec inter-chip gap between the UVIS CCDs in the combined image. As indicated in Table A.20, for a 2-arcsec offset maneuver, the three dithers will take 0.5 minutes each. Suppose we have determined that the exposure time necessary to reach the desired S/N ratio is 80 minutes, and that the visibility time at our target declination is 58 minutes. Furthermore, we will use the cosmic-ray removal provided by the dither data-reduction package, and therefore set CR-SPLIT=1. As a result, the orbit calculation will involve a sequence of four exposures of 20-minutes duration (i.e., one exposure at each of the four dither pointings). These observations will be distributed across two *HST* orbits, as shown in the following table:

Table A.20: Orbit Calculation for WFC3 Example 2

Action	Time (minutes)	Explanation
	Orbit 1	
Guide-star acquisition	6.0	Needed at start of observation of new target
UVIS overhead for first exposure	2.6	Includes filter change, camera set-up, and readout
UVIS overhead for second exposure	2.1	Includes readout
Spacecraft maneuver	0.5	To offset from first to second dither pointing
Two science exposures	$2 \times 20 = 40.0$	Exposures at the first two pointings in the dither pattern
Total time used in orbit 1	51.2	
	Orbit 2	
Guide-star re-acquisition	5.0	Needed at start of new orbit to observe same target
UVIS overheads for 3rd and 4th exposures	$2 \times 2.1 = 4.2$	Includes readouts
Spacecraft maneuvers	$2 \times 0.5 = 1.0$	To offset to the 3rd and 4th dither pointings
Two science exposures	$2 \times 20 = 40.0$	Exposures at the final two pointings in the dither pattern
Total time used in orbit 2	50.2	

No overhead is incurred to dump the exposures, because they are all longer than 339 seconds. Thus the desired exposures can be accomplished within the two orbits, and in fact there are ~7-8 minutes of unused visibility time per orbit that could be used to increase the exposure times.

APPENDIX B:

HST Mission

In this appendix...

B.1 Servicing Missions and Instrument Complements / 77

B.1 Servicing Missions and Instrument Complements

The Hubble Space Telescope is a cooperative project of the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) to operate a long-lived space-based observatory for the benefit of the international astronomical community. *HST* was first dreamt of in the 1940s and designed and built in the 1970s and 80s. In April 1990 the Space Shuttle Discovery deployed it in low-Earth orbit (~ 600 kilometers). The initial complement of Scientific Instruments (SIs) was:

- The Fine Guidance Sensors (FGSs).
- The Faint Object Camera (FOC).
- The Faint Object Spectrograph (FOS).
- The Goddard High Resolution Spectrograph (GHRS).
- The High Speed Photometer (HSP).
- The Wide Field and Planetary Camera (WF/PC).

Soon after deployment, it was discovered that the primary mirror suffers from spherical aberration, which limited the quality of *HST* data obtained in the first few years of operation.

B.1.1 Servicing Mission 1 (SM1)

During servicing mission SM1 in December 1993, Space Shuttle astronauts successfully refurbished *HST*. They replaced the HSP with COSTAR, a corrective optics package. COSTAR's reflecting optics were deployed into the optical paths of the

FOC, FOS, and GHRS, which removed the effects of the primary mirror's spherical aberration. The performance of the FGSs was unaffected by COSTAR. The WF/PC was replaced by a new instrument:

- The Wide Field and Planetary Camera 2 (WFPC2).

The WFPC2 contains its own internal optics to correct the spherical aberration of the primary mirror.

The astronauts also installed new solar arrays. This resolved the problem of thermal vibrations, which affected the old arrays during day/night transitions and, in turn, degraded the telescope's pointing performance.

B.1.2 Servicing Mission 2 (SM2)

During servicing mission SM2 in February 1997, astronauts replaced the FOS and the GHRS with two new instruments:

- The Near Infrared Camera and Multi-Object Spectrometer (NICMOS).
- The Space Telescope Imaging Spectrograph (STIS).

Also, FGS-1 was replaced with an enhanced FGS, called FGS1R. FGS1R has an adjustable fold flat mirror, which is commandable from the ground. This enables realignment in the FGS optical path to lessen the effects of the primary mirror's spherical aberration. As a result, the astrometric performance of FGS1R significantly exceeds that of the original FGS. FGS1R then became the primary science FGS.

B.1.3 Loss and Recovery of NICMOS

Just after launch during SM2, a thermal short in the NICMOS dewar caused the early exhaustion of its solid nitrogen cryogen, reducing the lifetime of the instrument to only about 2 years. The cryogen depleted in January 1999. During SM3B, the installation of the NICMOS Cooling System (NCS), a mechanical cryo cooler, re-enabled NICMOS operation, and restored infrared capability to *HST*. NICMOS was therefore unavailable for science operation between January 1999 and June 2002, from mid-Cycle 8 through Cycle 10, after which the NCS was activated and reached expected operating temperatures. The detector temperature has since been maintained at a slightly warmer temperature than before, so many NICMOS parameters are different. Most notably the detector quantum efficiency (DQE) increased by ~30–50%.

B.1.4 Servicing Missions 3A (SM3A) and 3B (SM3B)

HST has six rate-sensing gyroscopes on board. In the years after SM2, gyroscopes failed at a higher-than-expected rate, ultimately leading to a halt of *HST* observing in

November 1999. In anticipation of this event servicing mission SM3, which had been in planning for several years, was split into two separate missions: SM3A and SM3B.

SM3A

In December 1999 Space Shuttle astronauts lifted off for servicing mission SM3A. Six new gyroscopes were successfully installed, which allowed *HST* to resume normal operations.

Along with the gyro replacements, the *HST* Project used this "unplanned" mission to make other planned upgrades and refurbishments:

1. Voltage/temperature Improvement Kits (VIKs) were installed to help regulate battery recharge voltages and temperatures.
2. The original DF224 spacecraft computer was replaced by a 486 upgrade, which provides a significant improvement in onboard computing power.
3. The FGS2 was replaced by a refurbished fine guidance sensor FGS2R to enhance the performance of the pointing and control system (see section B.1.2). However, FGS1R remains the best choice for science observations due to its superior angular resolution.
4. The second tape recorder was replaced by a second Solid State Recorder (SSR), and a new transmitter was installed to replace one that had failed.

All of the upgrades underwent successful in-orbit verification and calibration and the observatory's functionality was completely restored according to plan.

SM3B

Servicing Mission 3B was carried out during the first ten days of March 2002. During this mission, astronauts replaced the FOC with a new instrument:

- The Advanced Camera for Surveys (ACS).

Also, the astronauts installed the NICMOS Cooling System (NCS) to allow further use of NICMOS, which had exhausted its cryogen in January 1999. Installation of new solar arrays, electrical upgrades to the spacecraft's power control unit, along with various other engineering upgrades including an orbit reboost, were performed. After the servicing mission, the ACS and NICMOS instruments, as well as STIS and WFPC2, remained fully commissioned for science until the loss of STIS in August of 2004.

B.1.5 Loss of STIS

The Space Telescope Imaging Spectrograph (STIS) Side-2 electronics failed in August of 2004, during Cycle 13. The instrument was maintained in safe mode until SM4.

B.1.6 Loss of ACS Wide Field Camera and High Resolution Camera

During Cycle 15, ACS WFC and HRC became unavailable for observations due to a failure in the electronics. The two cameras remained powered off until SM4.

B.1.7 SM4

Servicing Mission 4 occurred in May of 2009. Please refer to Section 1.2 of this document for details on the SM4 Mission. Cycle 18 offers the repaired ACS/WFC camera and the STIS instrument, the FGS plus two new instruments, COS and WFC3. The ACS/HRC could not be recovered during SM4 and is not operational. The WFPC2 was removed from *HST* during SM4. The observatory is expected to continue to operate in three-gyro mode for the foreseeable future.

APPENDIX C:

Legacy Instruments

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C.1 Faint Object Camera (FOC)

The FOC was designed to provide high-resolution images of small fields. It consisted of two independent optical relays that magnified the input beam by a factor of four (f/96) and two (f/48). A variety of filters, prisms (for slitless spectroscopy), and polarizers could be placed in the optical beam. The f/48 relay also had a longslit spectrograph. The FOC photocathodes limited the wavelength range from 1200 to 6000Å.

When corrected by COSTAR, the field-of-view (FOV) and pixel size of the f/96 camera were 7" x 7" (512 x 512 format) and 0.014" x 0.014", respectively; a field of 14" x 14" could be used with the 512 x 1024 pixel format and a rectangular pixel size of 0.028" x 0.014". Without COSTAR in the beam, the corresponding parameters for the f/96 camera were: 11" x 11" FOV in the 512 x 512 format with pixel size 0.0223" x 0.0223", and full-format field of 22" x 22" with 0.0446" x 0.0223" pixels. The corresponding values for the (little used) f/48 camera were twice those of the f/96 camera.

The f/96 camera was the primary FOC imaging workhorse. High voltage instabilities limited the use of the f/48 relay to mainly long-slit spectroscopy after the installation of COSTAR.

Most of the FOC data in the archive are unique because the spatial resolution of the FOC is greater than that of any other *HST* instrument. Also, the UV sensitivity was significantly higher than WFPC2, but less than STIS, although a larger variety of filters was available. Finally, the polarizers in the f/96 relay had very low instrumental polarization and excellent polarizing efficiencies.

A major reprocessing of the entire FOC science archive (science and non-science data) has been completed by ST-ECF, CADC, and STScI. This effort substantially improves the data quality and homogeneity. For more information about the reprocessed data, see Instrument Science Report FOC-99. The FOC data can be retrieved currently through the HSTonline interface at MAST.

C.2 Faint Object Spectrograph (FOS)

The FOS performed low and moderate resolution spectroscopy (R ~ 250 and 1300) in the wavelength range 1150 to 8500Å. A variety of apertures of different sizes and shapes were available which could optimize throughput and spectral or spatial resolution. Ultraviolet linear and circular spectropolarimetric capability was also available.

The low resolution mode had two gratings and a prism, and the R = 1300 mode had six gratings to cover the entire spectral range. The photon-counting detectors consisted of two 512-element Digicons, one which operated from 1150 to 5500Å (FOS/BLUE), and the other from 1620 to 8500Å (FOS/RED).

Most FOS data were acquired in accumulation and rapid-readout modes; periodic and image modes were used infrequently. Time resolutions as short as 30 msec were feasible. The electron image was magnetically stepped through a programmed pattern during the observations which provided for oversampling, compensation for sensitivity variations along the Digicon array, sky measures and/or measurement of orthogonally polarized spectra. Normally, data were read out in intervals that were short compared to the exposure time.

The FOS received about 20–25% of the total *HST* observing time over Cycles 1–6, studying a large and diverse range of science topics. Due to the polarimetric and large dynamic range capabilities, a substantial fraction of these data is and will remain unique.

A major reprocessing of the entire FOS archive, which has substantially improved the data quality and homogeneity, has been completed at the Space Telescope-European Coordinating Facility. These data have been incorporated into the *HST* Archive and are delivered routinely, through the *HST* online interface at MAST.

C.3 Goddard High Resolution Spectrograph (GHRS)

The GHRS had two, 500-element Digicon detectors, which provided sensitivity from 1100 to 1900Å (Side 1—solar blind) and 1150 to 3200Å (Side 2); these detectors offered photon-noise limited data if an observing strategy was undertaken to map out photocathode response irregularities with the FP-SPLIT option. Signal-to-noise ratios of 100 or more were routinely achieved, and upwards of 1000 on occasion.

The GHRS modes included a first order grating covering 1100–1900Å at R ~ 2,500 (285Å bandpass), four first order holographic gratings with very low scattered light covering 1150–3200Å at R ~ 25,000 (27–45Å bandpass), and cross-dispersed echelles at R ~ 80,000 over 1150–3200Å (6–15Å bandpass).

The GHRS had two apertures: the 2.0" Large Science Aperture (LSA), and 0.25" Small Science Aperture (SSA); post-COSTAR the aperture projections were reduced to 1.74" and 0.22", respectively. The SSA projected to one resolution element; thus, even pre-COSTAR data taken with this aperture had the designed spectral resolution, albeit at reduced throughput.

Some data were acquired at time resolutions as short as 50 milli-seconds in a Rapid Readout mode. Most observations were acquired in accumulation mode, which provided for oversampling, compensation for sensitivity variations along the Digicon array, and simultaneous monitoring of detector backgrounds. Routine observations of the onboard Pt-Ne emission line lamp provided data with well calibrated wavelengths.

The GHRS received about 20–25% of the total *HST* observing time over Cycles 1 through 6, resulting in a large and diverse range of high quality science data. Due to the high signal-to-noise ratio and large dynamic range capabilities in the far ultraviolet, much of these data are unique.

A major reprocessing of the entire GHRS archive (science and non-science data) has been completed by ST-ECF, CADC, and STScI. This effort substantially improves the data quality and homogeneity. For more information about the reprocessed data, see Instrument Science Report GHRS-92. The science data can be retrieved currently through the HSTonline interface at MAST.

C.4 High Speed Photometer (HSP)

The HSP was designed to take advantage of the lack of atmospheric scintillation for a telescope in orbit, as well as to provide good ultraviolet performance. Integrations as short as 10 μs were possible over a broad wavelength range (1200 to 8000Å), and polarimetry was also possible. Observations were carried out through aperture diameters of 1.0" with the visual and ultraviolet detectors, and 0.65" with the polarimetry detector.

HSP had a large variety of fixed aperture/filter combinations distributed in the focal plane; selection was accomplished by moving the telescope so as to place the target in the desired aperture behind the desired filter.

The HSP detectors consisted of four image-dissector tubes and one photomultiplier tube. A variety of ultraviolet and visual filters and polarizers was available. This instrument was used for only a relatively small fraction (5%) of *HST* observing in Cycles 1 to 3, since the HSP science program was among the more severely compromised by spherical aberration. Only limited instrument expertise is available at STScI in support of HSP Archival Research. The extremely high speed with which some HSP data were acquired remains unmatched by all other *HST* instruments.

C.5 Wide Field and Planetary Camera 1 (WF/PC)

The WF/PC had two configurations; in both, the FOV was covered by a mosaic of four charge-coupled devices (CCDs). Each CCD had 800 × 800 pixels and was sensitive from 1150 to 11,000Å. However, internal contaminants on the camera optics limited normal operation to the range from 2840 to 11,000Å.

In the Wide Field Camera (low-resolution) configuration, the FOV was 2.6' x 2.6', with a pixel size of 0.10". In the Planetary Camera (high-resolution) configuration, the FOV was 1.1' x 1.1' and the pixel size was 0.043". A variety of filters was available. The WF/PC received about 40% of the observing time on *HST* in Cycles 1 to 3, resulting in a large and diverse range of science data. All WF/PC data were severely affected by the spherical aberration. Unique and valuable data exist in the archive, but in terms of photometric accuracy, and especially image quality, imaging daata taken after the first servicing mission are superior.

C.6 Wide Field and Planetary Camera 2 (WFPC2)

The WFPC2 was retired during SM4, but data from the instrument will continue to be available for archival research. It had three “wide-field” CCDs and one high-resolution (or “planetary”) CCD. Each CCD covered 800 x 800 pixels and was sensitive from 1150 to 11,000 Å. All four CCDs were exposed simultaneously, with the target of interest being placed as desired within the FOV.

The three Wide Field Camera (WFC) CCDs were arranged in an “L”-shaped FOV whose long side projects to 2.5', with a projected pixel size of 0.10". The Planetary Camera (PC) CCD had a FOV of 35" x 35", and a projected pixel size of 0.0455". The WFC configuration provided the larger FOV, but undersampled the cores of stellar images; the PC configuration sampled the images better, but had the smaller FOV.

A total of 48 different filters could be inserted into the optical path. Polarimetry could be performed by placing a polarizer quad filter into the beam and exposing through the different quads and/or different filter wheel rotations. There were a total of 18 narrow-band and medium-band filters, as well as 2 narrow-band quad filters that each yielded 4 different central wavelengths. There were also 4 linear ramp filters that effectively allowed imaging of a ~ 10" region in an arbitrary 1.3% bandpass at any wavelength between 3700Å and 9760Å, by means of a variety of filter wheel orientations and target placements within the FOV.

Beginning in 2003 a serious electronic anomaly appeared in the WF4 CCD detector of WFPC2 wherein sporadic images had corrupted (but correctable) photometry. The frequency and severity of the problem increased slowly, and by late 2005 a significant fraction of images taken in WF4 were blank and unusable. Early in 2006 a work-around was found, which allowed good data to be taken even though the WF4 electronics continued to slowly fail. WF4 continued to produce good data for several more years. The other three CCDs appeared unaffected, and in fact small targets were usually placed on the PC1 or WF3 CCDs, so the WF4 anomaly has had much less impact than it otherwise could have.

C.7 The Advanced Camera for Surveys High Resolution Channel (ACS/HRC)

The ACS High Resolution Channel (HRC) provided high-resolution, near-UV to near-IR imaging in Cycle 11 through 14. The HRC observations occupied approximately 8% of all *HST* science orbits during this time. The HRC detector was a 1K by 1K, thinned and backside-illuminated, SITe CCD with a near-ultraviolet optimized coating and 21 x 21 μm pixels, that provided ~0.028 x 0.025 arcsec/pixel spatial resolution. This format yielded a nominal 29 x 26 arcsec field of view. The spectral response of the HRC ranged from ~1700 Å to ~11,000 Å, and it had a peak efficiency of 29% at ~ 6500 Å (including OTA throughput).

The HRC PSF was critically sampled at 6300 Å and was undersampled by a factor 3 at 2000 Å. Well-dithered observations with the HRC led to a reconstructed PSF FWHM of 0.03" at ~400 nm, which increased towards longer wavelengths.

The HRC utilized the same narrow-band and broad-band filters available with the ACS Wide Field Camera (WFC).

The HRC also offered several optics that complemented HRC's field of view and UV sensitivity, but also permitted vignetted WFC imaging. These HRC-specific optics included UV and visible polarizers, a prism (PR200L), three medium-broad UV filters (F330W, F250W, and F220W) and two narrow band filters (F344N and F892N). HRC could also use the FR459M and FR914M broad ramp filters, as well as the FR505N [OIII], FR388N [OII], and FR656N (H alpha) narrow ramp filters.

The coronagraphic mode of ACS HRC allowed high-contrast imaging of faint circumstellar or circumnuclear sources, such as circumstellar debris disks and planetary companions, by preventing saturation of the detector and suppressing the diffraction pattern of the bright central source. The coronagraph featured a Lyot stop and two occulting disks that could be deployed into the field of view on demand. Finally, the HRC allowed low-dispersion (R~100) slitless spectroscopy with the G800L grism (~23 Å/pix in first order from 5500 to 10500 Å) and the PR200L prism (~21 Å/pix from ~3500 Å to the UV cut-off).

APPENDIX D:

Internet Links

ACS Dither Web Page

http://www.stsci.edu/hst/acs/proposing/dither

ACS Instrument

http://www.stsci.edu/hst/acs/

ACS Instrument Handbook

http://www.stsci.edu/hst/acs/documents/handbooks/cycle18/cover.html

Astronomer's Proposal Tool (APT)

http://www.stsci.edu/hst/proposing/apt

Canadian Astronomy Data Centre

http://cadcwww.hia.nrc.ca/

COS Instrument

http://www.stsci.edu/hst/cos/

COS Instrument Handbook

http://www.stsci.edu/hst/cos/documents/handbooks/current/cos_cover.html

Cycle 18 Announcement Web Page

http://www.stsci.edu/hst/proposing/docs/cycle18announce

Cycle 18 Call for Proposals

http://www.stsci.edu/hst/proposing/documents/cp/cp_cover.html

Digitized Sky Survey (DSS)

http://archive.stsci.edu/dss/

Exposure Time Calculators Web page:

http://etc.stsci.edu/webetc/index.jsp

Fine Guidance Sensor Instrument

http://www.stsci.edu/hst/fgs/

Fine Guidance Sensor Instrument Handbook

http://www.stsci.edu/hst/fgs/documents/instrumenthandbook

Hubble Legacy Archive

http:///hla.stsci.edu

High Level Science Products

http://archive.stsci.edu/hlsp/index.html

***HST* Data Handbook**

http://www.stsci.edu/hst/HST_overview/documents/datahandbook/

***HST* Dither Handbook**

http://www.stsci.edu/hst/HST_overview/documents/dither_handbook

***HST* Instrument Handbooks**

http://www.stsci.edu/hst/HST_overview/documents

***HST* Online**

http://archive.stsci.edu/hstonline/search.php

***HST* Science Instruments**

http://www.stsci.edu/hst/HST_overview/instruments

Image Reduction and Analysis Facility (IRAF)

http://iraf.noao.edu/

MultiDrizzle

http://stsdas.stsci.edu/pydrizzle/multidrizzle/

Multimission Archive Web Page (MAST)

http://archive.stsci.edu/

NASA/IPAC Extragalactic Database (NED)

http://nedwww.ipac.caltech.edu/

NICMOS Instrument

http://www.stsci.edu/hst/nicmos/

NICMOS Instrument Handbook

http://www.stsci.edu/hst/nicmos/documents/handbooks/current_NEW/cover.html

Parallel Observations

http://www.stsci.edu/hst/HST_overview/documents/uir/UIR_Parallels.pdf

Phase I Proposal Roadmap

http://apst.stsci.edu/apt/external/help/roadmap1.html

Phase II Program Preparation

http://www.stsci.edu/hst/programs

PyRAF

http://www.stsci.edu/resources/software_hardware/pyraf

Set of Identifications, Measurements and Bibliography for Astronomical Data (SIMBAD)

http://simbad.u-strasbg.fr/Simbad

Space Telescope - European Coordinating Facility

http://www.stecf.org/

Space Telescope Science Data Analysis Software (STSDAS)

http://www.stsci.edu/resources/software_hardware/stsdas

Space Telescope Science Institute

http://www.stsci.edu/

StarView

http://starview.stsci.edu/

STIS Instrument

http://www.stsci.edu/hst/stis/

STIS Instrument Handbook

http://www.stsci.edu/hst/stis/documents/handbooks/currentIHB/stis_ihbTOC.html

Tiny Tim

http://www.stecf.org/instruments/TinyTim/

Visit Size Recommendations

http://www.stsci.edu/hst/programs/recommendations

WFC3 Instrument

http://www.stsci.edu/hst/wfc3/

WFC3 Instrument Handbook

http://www.stsci.edu/hst/wfc3/documents/handbook/cycle18/wfc3_cover.html

WFPC2 Instrument

http://www.stsci.edu/hst/wfpc2/

WFPC2 Instrument Handbook

http://www.stsci.edu/hst/wfpc2/documents/handbook/cycle18/cover.html

APPENDIX E:

Glossary of Acronyms and Abbreviations

ACQ	Acquisition
ACS	Advanced Camera for Surveys
APT	Astronomer's Proposal Tool
BOP	Bright Object Protection
CADC	Canadian Astronomy Data Centre
CCD	Charge-Coupled Device
COS	Cosmic Origins Spectrograph
COSTAR	Corrective Optics Space Telescope Axial Replacement
CTE	Charge Transfer Efficiency
CVZ	Continuous Viewing Zone
DADS	Data Archive and Distribution System
DD	Director's Discretionary
DQE	Detector Quantum Efficiency
DSS	Digitized Sky Survey
ESA	European Space Agency
ETC	Exposure Time Calculator
FGS	Fine Guidance Sensor(s)
FITS	Flexible Image Transport System
FOC	Faint Object Camera
FOS	Faint Object Spectrograph
FOV	field-of-view

FUV	Far Ultraviolet
GHRS	Goddard High Resolution Spectrograph
GO	General Observer
GSC	Guide Star Catalog
GSFC	Goddard Space Flight Center
GTO	Guaranteed Time Observer
HLA	Hubble Legacy Archive
HLSP	High Level Science Products
HSP	High Speed Photometer
HST	Hubble Space Telescope
HTML	Hyper Text Markup Language
IFOV	Instantaneous field-of-view
IRAF	Image Reduction and Analysis Facility
ISR	Instrument Science Report
LRF	Linear Ramp Filter
MAMA	Multi-Anode Microchannel Array
mas	milli arcsecond
MAST	Multimission Archive at STScI
NASA	National Aeronautics and Space Administration
NED	NASA/IPAC Extragalactic Database
NCS	NICMOS Cooling System
NICMOS	Near Infrared Camera and Multi-Object Spectrometer
NOAO	National Optical Astronomy Observatories
NUV	Near Ultraviolet
OMS	Observatory Monitoring System
OTA	Optical Telescope Assembly
OTFR	On The Fly Reprocessing
PAM	Pupil Alignment Mechanism
PC	Planetary Camera
PCS	Pointing Control System
PDF	Portable Document Format
PI	Principal Investigator
POS	Position Mode

PSF	Point Spread Function
SAA	South Atlantic Anomaly
SAM	Small Angle Maneuver
SBC	Solar Blind Channel
SI	Scientific Instrument
SIMBAD	Set of Identifications, Measurements and Bibliography for Astronomical Data
SM	Servicing Mission
SSM	Support Systems Module
SSR	Solid State Recorder
ST-ECF	Space Telescope - European Coordinating Facility
STIS	Space Telescope Imaging Spectrograph
STOCC	Space Telescope Operations Control Center
STScI	Space Telescope Science Institute
STSDAS	Space Telescope Science Data Analysis Software
TDRSS	Tracking and Data Relay Satellite System
TRANS	Transfer Mode
UIR	User Information Report
UV	Ultraviolet
VIK	Voltage/Temperature Improvement Kit
WFC	Wide Field Camera (on WFPC2) or Wide Field Channel (on ACS)
WFC3	Wide Field Camera 3
WF/PC	Wide Field and Planetary Camera 1
WFPC2	Wide Field and Planetary Camera 2