Version 3.0
October 2006

HST Two-Gyro Handbook

Space Telescope Science Institute
3700 San Martin Drive
Baltimore, Maryland 21218
help@stsci.edu

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

User Support

For prompt answers to any question related to Hubble Space Telescope observations, contact the Space Telescope Science Institute Help Desk at

- **E-mail:** help@stsci.edu
- **Phone:** (410) 338-1082
  (800) 544-8125 (U.S., toll free)

The Space Telescope European Coordinating Facility (ST-ECF) also maintains a Help Desk. European users can contact the ST-ECF for help at

- **E-mail:** stdesk@eso.org

World Wide Web

Information and other resources are available on the HST web site

- **URL:** http://www.stsci.edu/hst

and the HST Two-Gyro Science Mode web site:

- **URL:** http://www.stsci.edu/hst/HST_overview/TwoGyroMode

Proposers are encouraged to check the Two-Gyro Science Mode web site for updates related to two-gyro operations.

Revision History

Version	Date	Editors
3.0	October 2006	Sembach, K.R., et al
2.0	October 2005	Sembach, K.R., et al.
1.0	October 2004	Sembach, K.R., et al.

Citation

In publications, refer to this document as:
Sembach, K. R., et al. 2006, "HST Two-Gyro Handbook", Version 3.0, (Baltimore: STScI)

Send comments or corrections to:
Space Telescope Science Institute
3700 San Martin Drive
Baltimore, Maryland 21218
E-mail:help@stsci.edu

Table of Contents

Acknowledgments

The information in this Handbook is a brief summary of the experience gained by many individuals working on the HST two-gyro mode development at STScI and elsewhere. Some of the material contained herein is based upon results of the February 2005 two-gyro on-orbit test, the August 2005 two-gyro transition orbital verification, and information presented at the HST Two-Gyro Phase I Design Review (February 2004) and Critical Design Review (July 2004). Additional material related to guiding performance and pointing jitter is derived from analyses of HST pointing control simulations performed by the HST Pointing and Control Systems group at Lockheed Martin Technical Operations Company. We thank all of the individuals and groups involved in these design reviews and simulations for their efforts. We especially thank Brian Clapp for his efforts in leading the simulation efforts.

The STScI Two-Gyro Team, which assessed the instrument performance results from the February 2005 tests and August 2005 orbital verification, included: Santiago Arribas, Ed Bergeron, Carl Biagetti, John Biretta, Colin Cox, Roelof de Jong, Rodger Doxsey, Ron Gilliland, Anton Koekemoer, Vera Kozhurina-Platais, Ray Lucas, Jennifer Mack, Sangeeta Malhotra, Ed Nelan, Keith Noll, Cheryl Pavlovsky, Adam Riess, Kailash Sahu, Glenn Schneider (U. Arizona), Ken Sembach, Marco Sirianni, Tommy Wiklind, and Chun Xu. The STScI Two-Gyro Planning Team for the February 2005 and August 2005 tests included Allison Vick, George Chapman, and Merle Reinhart.

We thank Ron Downes for assistance with the graphical material in the observation planning portion of the Handbook. We thank Susan Rose and Jim Younger for their assistance with the hardcopy and web-based production of the Handbook.

CHAPTER 1:

Introduction to Two Gyro-Mode

In this chapter. . .

1.1 Introduction

This Handbook is a shortened edition of versions that were released previously. It contains only the basic two-gyro information needed to submit your Phase I proposal. Observers interested in the HST gyroscopes, slewing and guide star acquisition processes in two-gyro mode, and the impact of observatory disturbances on HST pointing should consult earlier versions of the Handbook.

The Hubble Space Telescope was originally designed to use three rate-sensing gyroscopes to provide fine pointing control of the observatory during science observations. In order to conserve the lifetime of the HST gyros, one of the functioning gyros was turned off on 28-August-2005 and a new attitude control system that functions with only two gyros was activated. In this mode, two gyros used in combination with the Fine

Guidance Sensors provide fine-pointing information during science observations.

The *HST Two-Gyro Handbook* contains information about target visibility and scheduling of HST observations conducted with an attitude control system relying upon just two gyroscopes. Use the Handbook in conjunction with the appropriate Instrument Handbooks and the *Hubble Space Telescope Call for Proposals* and *Hubble Space Telescope Primer* when assembling your Cycle 16 Phase I proposal. The individual Instrument Handbooks contain detailed technical information about the science instruments and their on-orbit performance. The *Call for Proposals* contains policies and instructions for proposing.

1.2 Two-Gyro Pointing Jitter and Image Quality

Initial on-orbit tests of the HST two-gyro fine guiding mode and its impact on science instrument performance were carried out on 20-23 February 2005. Gyro #1 was removed from the pointing control loop, and Gyros #2 and #4 were used with the FGS to control the HST attitude during all science observations. The excellent pointing stability observed in fine lock during these tests was confirmed as part of the two-gyro transition orbital verification activities in August 2005 with a different pair of gyros (Gyros #1 and #2). The HST Project decided to turn off Gyro #4 on 28-August-2005 to extend its lifetime in case it is needed in the future.

HST fine-pointing performance in two-gyro mode is essentially indistinguishable from the fine-pointing performance observed previously in three-gyro mode.

Jitter Estimates

The HST Pointing and Control Systems group monitored the pointing jitter throughout the two-gyro on-orbit tests. For each science exposure, they calculated the jitter at 25 milli-second intervals as estimated by the attitude control law used to maintain the HST pointing. Summaries of the 10-second and 60-second jitter root-mean-square running averages and peak excursions are given in Table 1.1. This table lists the two-gyro 10-second and 60-second mean, median, and maximum jitter values for a sample of 454 exposures obtained in February 2005. Almost all of the exposures have a mean jitter less than 10 milli-arcseconds. In a few cases, transient pointing disturbances caused small enhancements in the jitter. These types of disturbances are also commonly seen in three-gyro mode.

Table 1.1: Jitter Measured During the February 2005 Two-Gyro On-Orbit Test

	Jitter (milli-arcseconds, RMS)			
	Avg 10-sec	**Peak 10-sec**	**Avg 60-sec**	**Peak 60-sec**
Two-Gyro Mean	5.6	6.5	6.0	6.2
Two-Gyro Median	5.5	6.2	5.7	6.0
Two-Gyro Maximum	9.5	22.2	10.7	18.0
Percentage of Two-Gyro Exposures with Jitter < 10 mas	100%	97.8%	99.1%	98.7%
Three-Gyro Mean	4.1	5.2	4.2	4.3

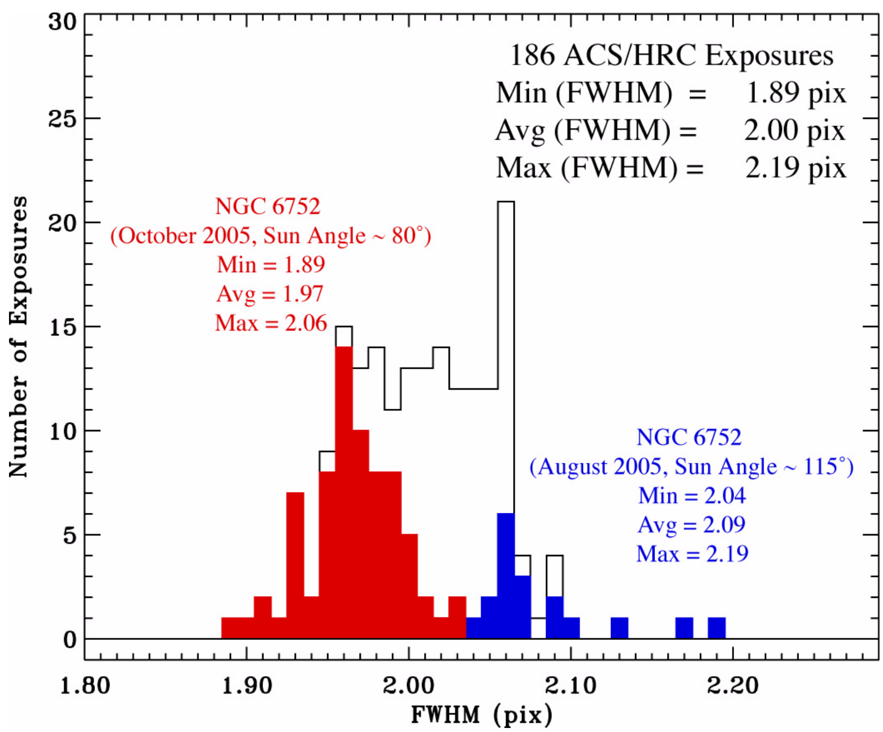
Notes: Two-gyro values are based on a sample of 454 exposures taken during the two-gyro on-orbit test (20-23 February 2005). Three-gyro values are based on a sample of 24 exposures taken several days prior to the two-gyro on-orbit test.

The mean two-gyro 60-second-averaged jitter in Table 1.1 is slightly higher than the mean 10-second-averaged jitter because the sample includes several series of short dithered exposures; the 60-second running averages span short periods of slightly increased jitter between exposures as the pointing was changed from one dither position to the next. Jitter values measured after the August 2005 transition to two-gyro mode are similar to the values listed in the table. The two-gyro jitter is comparable to the jitter observed in three-gyro mode.

Image Quality

The jitter observed in fine lock in two-gyro mode is small enough that it does not noticeably impact the quality of HST observations, even those obtained with the Advanced Camera for Surveys High Resolution Channel (ACS/HRC), which has a plate scale of ~25 milli-arcseconds per pixel. Figure 1.1 shows a histogram of point spread function (PSF) widths measured in 186 ACS/HRC exposures obtained during the two-gyro orbital verification in August 2005. The PSFs have full widths at half maximum intensity (FWHM) that range from 1.89 to 2.19 pixels (or 47-55 milli-arcseconds). This is indistinguishable from the resolution achievable in three-gyro mode. The tail of FHWM values above 2.07 pixels in this figure occurs for data taken at a larger Sun angle (~115˚) than the Sun angle for the remaining data (<90˚). Slight orbital variations in focus caused by telescope breathing and other effects are present in two-gyro data as well as previous three-gyro data.

Figure 1.1: ACS/HRC Point Spread Function Widths in Two-Gyro Mode



1.3 Guide Star Acquisitions

There have been no losses of fine lock resulting from large pointing disturbances during any of the science observations obtained to date in two-gyro mode. Loss of lock has occurred during guide star acquisitions, but most of these failures have been traced to either bad guide stars or to minor problems during the process of entering fine lock from coarser pointing conditions. The former problem of bad guide stars existed for three-gyro acquisitions as well, and should be alleviated in part by the use of the new *Guide Star Catalog 2*. The remaining problems have been largely overcome with minor changes to the flight software. The acquisition success rate in two-gyro mode is roughly 96%, compared to 98% previously in three-gyro mode.

1.4 Scheduling and Target Visibility

Observations with either orientation or timing constraints are more difficult to implement in two-gyro mode than in three-gyro mode because of the additional pointing restrictions necessary for attitude control and observatory safety. Roughly half the sky is visible at any point in time in two-gyro mode, compared to >80% of the sky in three-gyro mode.

Whenever possible, observers should try to minimize the number of scheduling requirements placed on their observations. This will result in improved schedulability and long range planning, and more efficient use of observing time. Descriptions and examples of how orientation and timing constraints can affect the scheduling of an object and its orbital visibility period can be found in Chapter 2.

Fixed Targets

Observers planning their Cycle 16 Phase I and Phase II proposals should consult Chapter 2, which describes the scheduling of observations in two-gyro mode. The information contained therein has not changed significantly since Cycle 15. The scheduling information should be used in conjunction with the visibility tools available on the Two-Gyro Science Mode web site and the Visit Planner in the Astronomers Proposal Tools (APT).

Moving Targets

Proposers wanting to observe moving targets should assume that observations in two-gyro mode will work exactly as they did for three-gyro mode, with the caveats that gyro-only tracking and guide star handoffs are not available in two-gyro mode. Moving targets are subject to the same general scheduling and visibility constraints as fixed targets (see Chapter 2). See the *Cycle 16 Call for Proposals* for additional restrictions on moving target observations.

Scheduling Efficiency

The scheduling efficiency of HST has remained high in two-gyro mode. During the past cycle, the first full cycle of two-gyro observations, the HST Scheduling Group was able to schedule ~71-73 two-gyro prime orbits per week compared to ~80 prime orbits per week in three-gyro mode. The scheduling efficiency of HST in Cycle 16 is expected to be similar.

The need to schedule prime science observations as efficiently as possible in two-gyro mode has resulted in a reduction in the completion rate of snapshot (SNAP) observations. This issue is being addressed through the introduction of the new Survey Proposal category described in the *Cycle 16 Call for Proposals*.

1.5 Science Instrument Performance

The science instrument performance in two-gyro mode is nearly indistinguishable from the science instrument performance in three-gyro mode. Refer to the appropriate Instrument Handbooks for information regarding the detailed on-orbit performance capabilities of the HST science instruments. Additional information about the performance in two-gyro mode can be found in the Instrument Science Reports listed below.

Instrument Science Reports

Characterization of the ACS/HRC PSF in Two-Gyro Mode, (ACS ISR 2006-08), by M. Sirianni et al.
http://www.stsci.edu/hst/acs/documents/isrs/isr0608.pdf

Two-Gyro Pointing Stability of HST Measured with ACS, (ACS ISR 2005-07), by A. Koekemoer, V. Kozhurina-Platais, A. Riess, M. Sirianni, J. Biretta, & C. Pavlovsky
http://www.stsci.edu/hst/acs/documents/isrs/isr0507.pdf

ACS Coronagraph Performance in Two-Gyro Mode, (ACS ISR 2005-05), by C. Cox & J. Biretta
http://www.stsci.edu/hst/acs/documents/isrs/isr0505.pdf

NICMOS Two-Gyro Mode Coronagraphic Performance, (NICMOS ISR 2005-001), by G. Schneider, A.B. Schultz, S. Malhotra, & I. Dashevsky
http://www.stsci.edu/hst/nicmos/documents/isrs/isr_2005_001.pdf

The FGS Astrometry in the Feb. 2005 On-Orbit Two-Gyro Mode Test, (FGS ISR 2005-01), by E. Nelan
http://www.stsci.edu/HST_overview/TwoGyroMode/documents/FGS.pdf

CHAPTER 2:

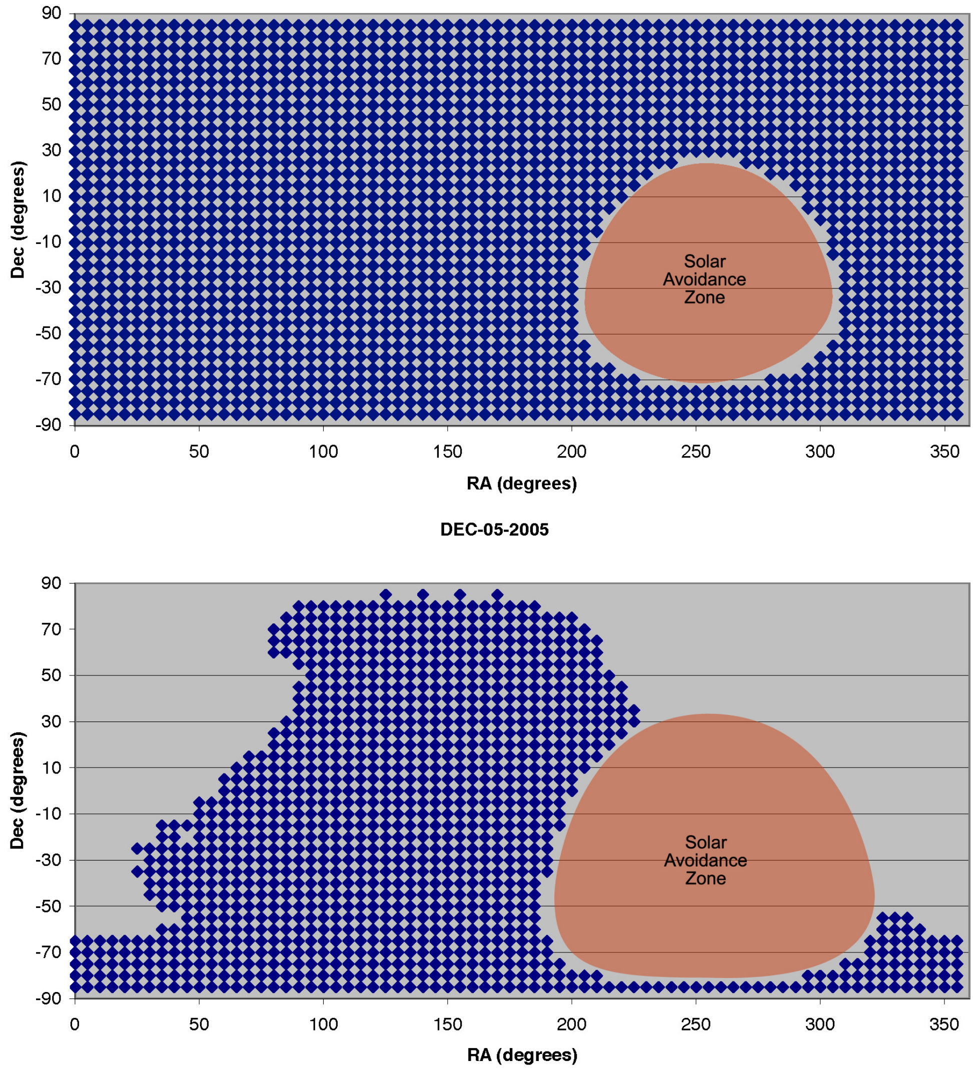
Planning Observations in Two-Gyro Mode

2.1 All-Sky Availability of Fixed Targets

2.1.1 Overview

The schedulability of an HST observation depends upon many factors and differs considerably between three-gyro and two-gyro operations. To briefly highlight some of these differences, it is useful to compare the accessible regions of the sky in the two modes on a given day of the year.

Figure 2.1: Sky Availability on 5 December 2005



Caption: Sky availability for 5 December 2005 in both three-gyro mode (top panel) and two-gyro mode (bottom panel).

Figure 2.1 shows the sky availability for a single day assuming attitude control with either three gyros (top panel) or two gyros (bottom panel). Blue regions indicate areas of the sky that can be observed on the date shown, while grey areas of the sky are not observable at that time. The unobservable region of sky is much larger in two-gyro mode than in three-gyro mode because of constraints imposed to achieve guide star acquisitions and to ensure the safety of the observatory. On any given day there is a region of the sky that cannot be observed in either two-gyro or three-gyro mode because of solar avoidance constraints. In three-gyro mode, all regions of the sky outside the solar avoidance zone (50 degree radius) are accessible on any day. The solar avoidance zone for two-gyro mode is larger, with a 60 degree radius. A large region of the sky ahead of the solar avoidance zone (at larger right ascensions than the Sun) is also unobservable in two-gyro mode because of constraints imposed by the process of correcting slew errors and achieving fine guiding lock. Thus, in two-gyro mode most targets can only be observed when they are on the trailing side of the Sun as it moves along the ecliptic. Over the course of the year, all areas of the sky are available in two-gyro mode, but the total time available in any given direction is less than in three-gyro mode.

2.1.2 All-sky Availability Movie

A short narrated movie showing the sky availability during the course of a year can be found on the web at:

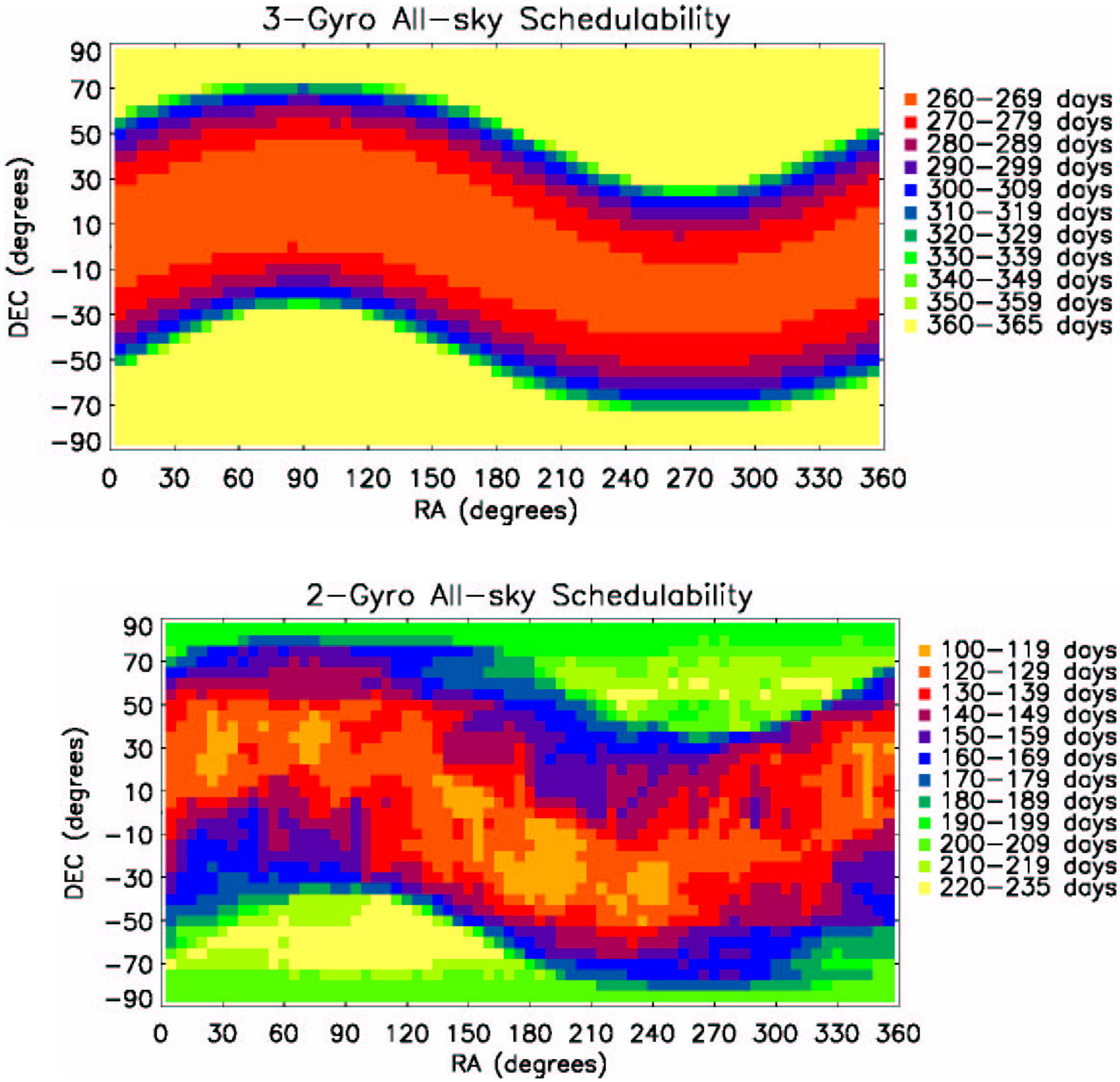
http://www.stsci.edu/hst/HST_overview/TwoGyroMode/2GyroMovies/2gyro.html

This movie compares the three-gyro and two-gyro availabilities in one-week increments in a format similar to the figure above. It shows the variable nature of the sky availability in two-gyro mode and the features discussed previously. It also shows that the availability near the equatorial poles is periodic and alternating. This availability pattern at high declinations is tied to the precession of the HST orbit.

2.1.3 Number of Available Days During the Course of a Year

It is useful to consider how many days per year a target of fixed position can be observed by HST. The top panel of Figure 2.2 shows the number of days in a cycle that any position in the sky is observable by HST with three-gyro pointing capabilities. This plot is essentially an encapsulation of the contents of the sky availability movie described above. The color-coding of this figure indicates the number of days for which at least one orbit (defined here to be a contiguous time block of at least 30 minutes) is available to observe a fixed target. In this figure, the allowable Sun angle range is 50-180 degrees. The fewest number of schedulable days occurs over a small swath of sky near the ecliptic, with availability increasing toward the equatorial poles. The minimum number of days available is approximately 260. A large portion of the sky at greater than 50 degrees ecliptic latitude has at least one schedulable orbit over the entire cycle duration. Be aware that this plot does not convey the information necessary to judge uninterrupted availability as occurs in the continuous viewing zones (CVZs). CVZ opportunities depend on a variety of additional factors that are described elsewhere (see the *HST Primer* and Section 2.5).

Figure 2.2: All-Sky Target Schedulability



The bottom panel of Figure 2.2 shows the number of days in a cycle that any position in the sky is observable with HST operating in two-gyro mode. Here, the allowable Sun angle range is restricted to 60-180 degrees. Note that the absolute level of the color scaling is different than it is in the three-gyro case shown in the top panel. There are several things worth noting about this panel when comparing it to the three-gyro results. First, and most importantly, the total number of schedulable days at all positions in the sky decreases substantially in two-gyro mode. Second, the smooth progression in availability seen in the top panel becomes slightly less regular, with pockets of reduced availability occurring across the sky. The overall trend for greater availability increasing toward the equatorial poles remains, but even some high declination pointings have fewer than half as many schedulable days as in three-gyro mode.

2.2 Scheduling Considerations and Visibility Periods for Fixed Targets

2.2.1 Overview

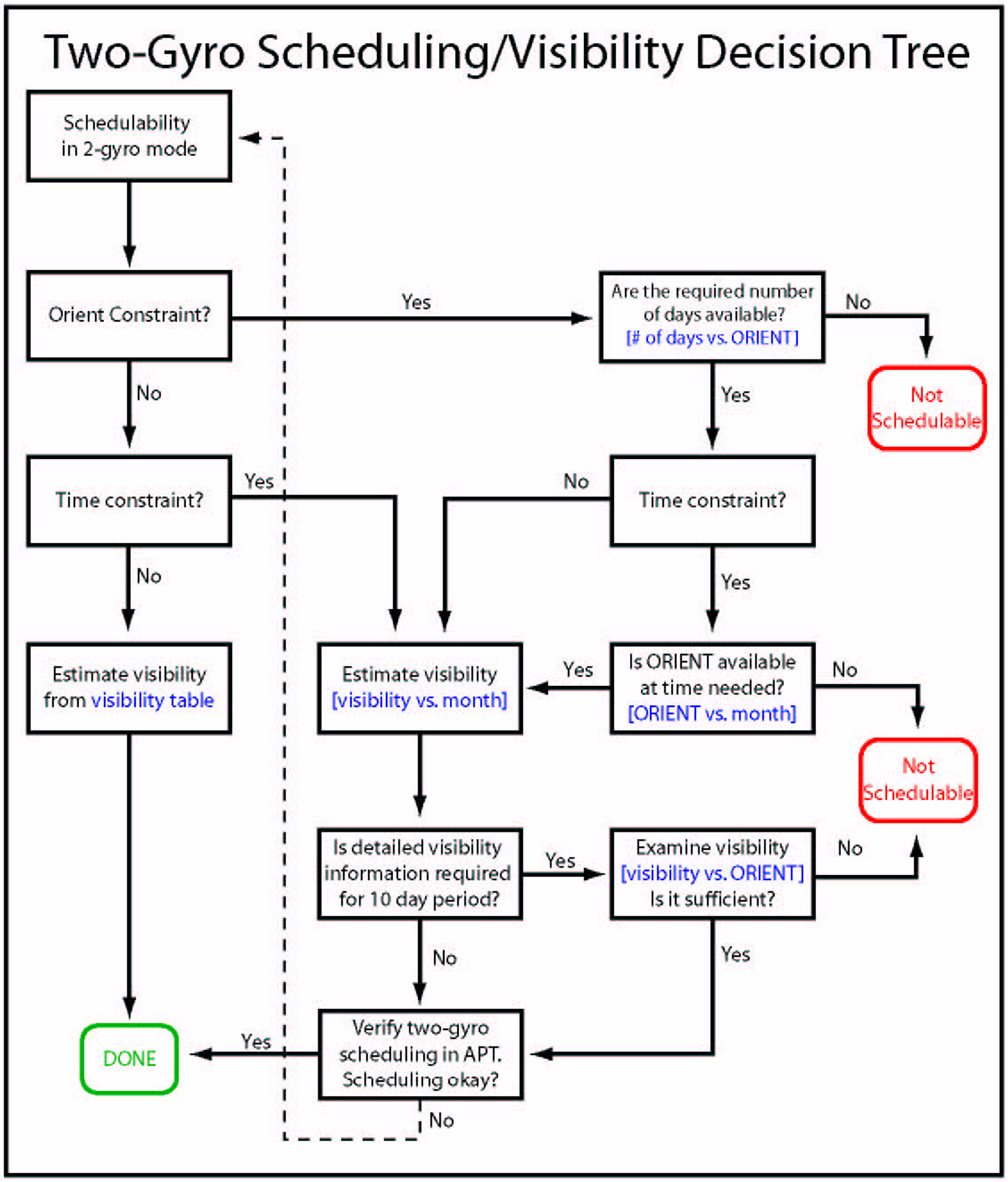
The primary observational constraints on the schedulability of most fixed targets in two-gyro mode are the position of the target in the sky, the required orientation or roll angle of the observatory (if any), and the required timing of the observation (if any). Orientation constraints are usually specified with the `ORIENT` special requirement and often involve a restricted range of allowable roll angles that correspond to a particular time period that HST is able to achieve this orientation. Timing requirements may be specified either implicitly through the `ORIENT` special requirement or explicitly through timing special requirements (e.g., `BETWEEN`, `AFTER`, etc.). In some cases, an observation may not be schedulable in two-gyro mode because of the restrictions imposed by orientation and/or timing special requirements.

Minimizing the number of special requirements on your observations will improve schedulability.

The operational definition of orbital visibility period for two-gyro operations is the same as it was for three-gyro operations. Orbital visibility is the unocculted time available during the orbit for guide star acquisitions (6 minutes), target acquisitions, science exposures, calibration exposures, and instrument overheads.

Figure 2.3 provides a graphical description of the general decision process involved in determining the schedulability and orbital visibility periods for fixed targets observed in two-gyro mode. The decision process for unconstrained observations involves minimal effort, whereas constrained observations require more careful consideration of the times of year that an observation can be scheduled. We discuss both types of observations below.

Figure 2.3: Two-Gyro Scheduling and Visibility Decision Tree



2.2.2 Unconstrained Fixed-Target Observations

If you do not need to specify the orientation of the observatory or the time of year of the observation, then the impact on scheduling is minimized and the observation will be schedulable at some time during the year. The orbital visibility of an unconstrained fixed-target is determined primarily by its declination. Table 2.1 lists the two-gyro orbital visibility periods as a function of declination. These average values are sufficient for Phase I orbit calculations.

Table 2.1: Standard Two-Gyro Fixed-Target Orbital Visibility Periods

Declination (degrees)	Orbital Visibility[1] (minutes)	LOW Visibility[2] (minutes)	SHADOW Visibility[3] (minutes)
0–5	52	47	25
5–15	52	47	25
15–25	53	48	25
25–35	53	48	25
35–45	53	48	25
45–55	54	45	25
55–65	54	45	25
65–75	55	43	25
≥75	57	42	25
Any CVZ	96	incompatible	incompatible

1. The orbital visibility periods in this table are the typical unocculted times available for guide star acquisitions and instrument-related activities.
2. LOW visibility refers to low-sky observations specified with the LOW special requirement.
3. SHADOW visibility refers to Earth-shadow observations specified with the SHADOW special requirement.

If your observation has no timing or orientation special requirements, the orbital visibility period can be found in Table 2.1, and you do not need to use the scheduling plots found later in this chapter or on the Two-Gyro Science Mode web site.

2.2.3 Constrained Fixed-Target Observations

If your science goals require specification of the orientation of the observatory and/or the timing of the observation, determinations of the schedulability and orbital visibility period are slightly more complicated. An on-line tool to help you determine when a fixed target can be scheduled during Cycle 16 is available on the Two-Gyro Science web page at:

http://www.stsci.edu/hst/HST_overview/TwoGyroMode/AllSkyInformation

Enter the coordinates of your target into the web form, and the tool provides several graphical products that can be used to assess when and for how long the target is visible. The calculations used to construct this output were performed on a 5°x5° grid on the sky. The output returned is appropriate for the grid point nearest the input coordinates. Thus, any input position is within 3.5 degrees of a grid point. This sampling is sufficient to provide accurate scheduling and visibility information for any position on the sky for the Phase I proposal process. The models used as input to produce this information rely upon realistic representations of the constraints expected for two-gyro operations. For clarity, Moon avoidance constraints are not included in these results; this does not alter the schedulability of a fixed-target or its orbital visibility significantly. Complete models including all constraints will be available for Phase II proposal processing.

The products returned by the Available Science Time and Orientation web tool include:

1. A plot and table of the total number of days per year that each orientation is available.
2. A plot and table of when each orientation is available during Cycle 16 and the first half of Cycle 17.
3. A plot and table of the target visibility as a function of date during Cycle 16 and the first half of Cycle 17.

The plots and tables contain information about the schedulability of the target and how much time per orbit is available for the observation. Examples of each of these plots and tables are discussed below.

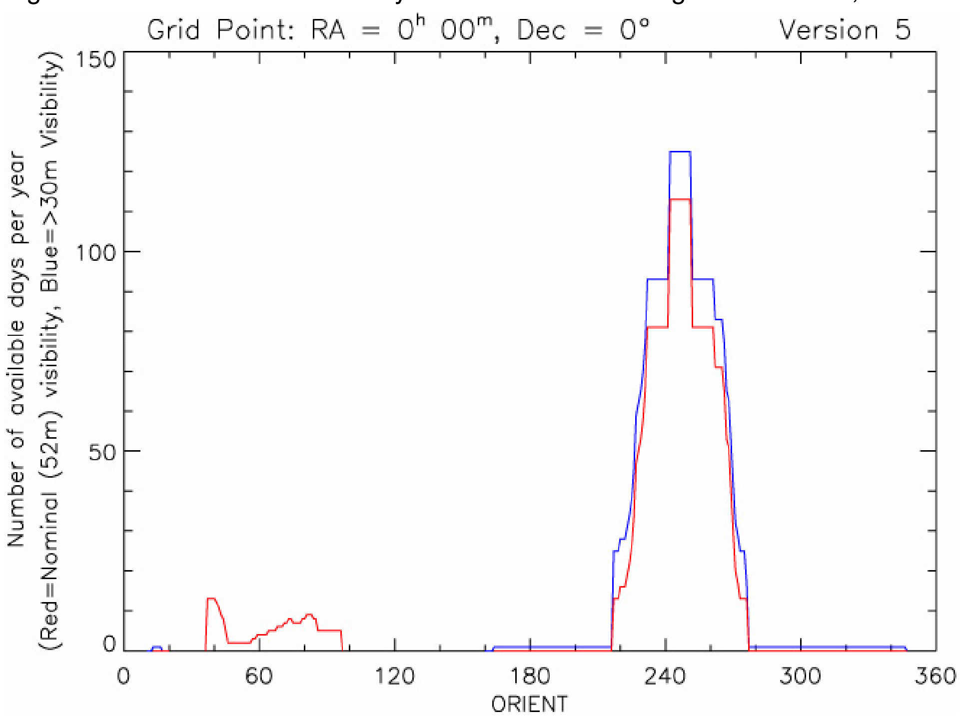
Plot Example: Number of Available Days as a Function of Orientation

The number of days that a particular HST orientation (roll angle) can be achieved in two-gyro mode in Cycle 16 is shown as a function of orientation for a low-latitude location ($\alpha = 0°$, $\delta = 0°$) in Figure 2.4 and for a high-latitude location ($\alpha = 0°$, $\delta = +70°$) in Figure 2.5. An available day is defined to be one in which at least one orbit with the nominal visibility listed in Table 2.1 exists (red curve in the figures). Some days may have only short visibility periods; for reference, the number of days with visibilities ≥30 minutes is also plotted in the figures (blue curve). A portion of the table returned by the web tool for the low latitude example is provided in Table 2.2.

The number of days of availability may be quite limited for some orientations, especially at low declinations, as a result of Sun angle constraints. The range of available orientations expands at higher latitudes, with the number of days of availability increasing for some orientations and decreasing for others. In some cases, the number of days available may be zero.

In the low latitude example in Figure 2.4, there is a restricted range of orientations over which the target is observable. There is minimal availability for orientations from 0˚-216˚ and from 277˚-360˚. There is a large window available for orientations centered around 245˚. Using orbits with less than the nominal (52 minute) visibility does not increase the availability significantly. Note that, unlike three-gyro operations, it is not possible to observe at orientations with a 180˚ separation.

Figure 2.4: Orientation Availability for a Low-Latitude Target Near $\alpha = 0˚$, $\delta = 0˚$

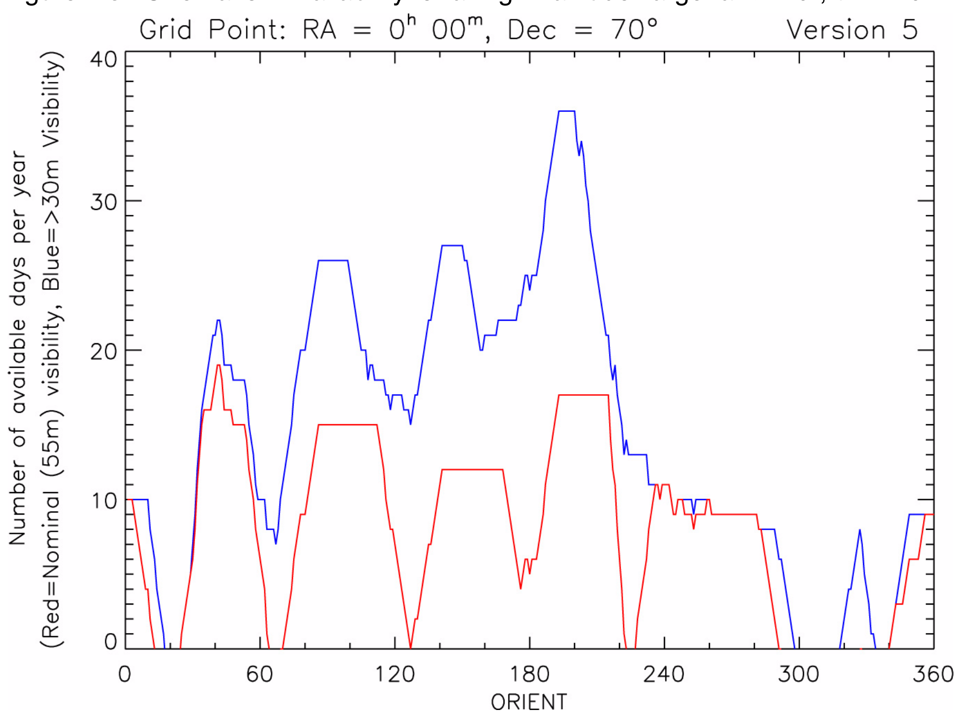


In the high latitude example in Figure 2.5, many orientations are available for ten or more days, with notable exceptions occurring over restricted ranges in orientation where the availability dips to zero. Unlike the low latitude case, there are several orientations (e.g., 180˚) for which the use of orbits with less than nominal (55 minute) visibility increases the availability; in some cases, the target is available only with these short orbits. However, scheduling these short orbits results in efficient use of the telescope. Requests for short orbits must be well-justified scientifically and are expected to be available only in exceptional cases.

Table 2.2: A Portion of the Tabular Output for the Data Shown in Figure 2.4

Grid Point: RA = 0^h 00^m, Dec = 0°		
Orientation Angle (deg)	**Number of Days Available (>30 min)**	**Number of Days Available (>52 min)**
:	:	:
262	83	71
263	83	71
264	83	71
265	83	71
266	77	65
267	65	53
268	63	51
269	53	41
270	42	30
271	32	20
272	29	17
:	:	:

Figure 2.5: Orientation Availability for a High-Latitude Target at $\alpha = 0^\circ$, $\delta = +70^\circ$

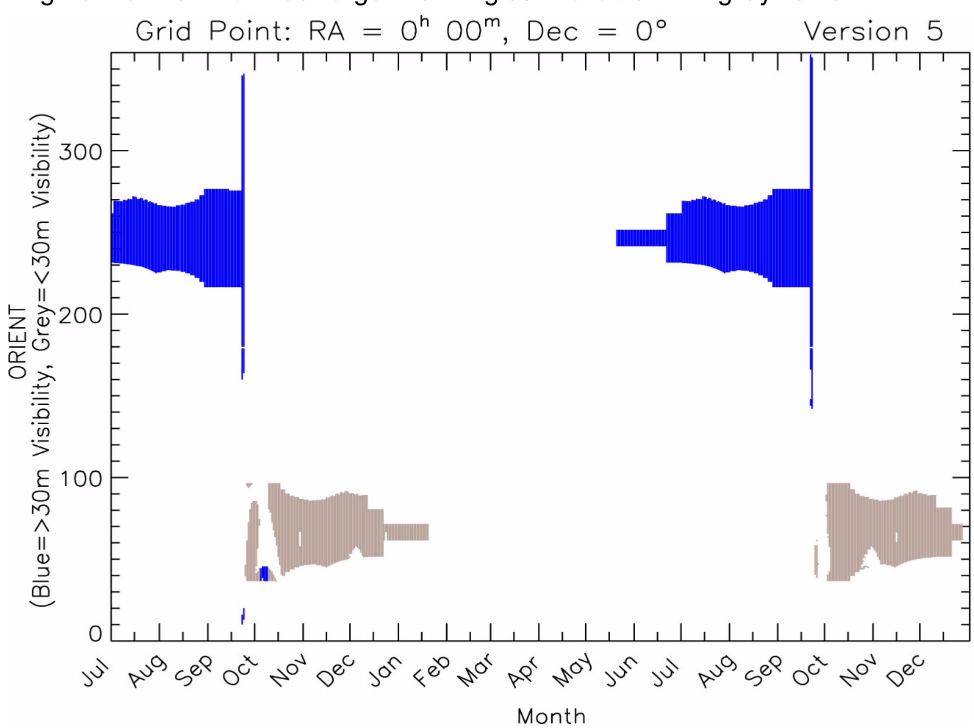


Plot Example: Availability of Roll Angles in Cycle 16

If a sufficient number of days exists to observe a target, the next step in determining its schedulability is to check when the target could be scheduled. If there are roll angle (`ORIENT`) constraints, you should check when the particular orientation is available by examining the web tool plot illustrating `ORIENT` versus time. Example plots are shown in Figure 2.6 and Figure 2.7, and a sample of the tabular output is shown in Table 2.3. The time axis on these plots extends for 18 months from the start of Cycle 16 (01-July-2007 to 31-Dec-2008) so that observers can judge whether observations that begin in Cycle 16 could be concluded in the first half of Cycle 17. The blue regions of the figures indicate what orientations are available for the specified date when there is at least one orbit with 30 minutes of visibility. The gold regions indicate less than 30 minutes of visibility for some ORIENTs on that date. Note that most orientations are available only for limited periods of time.

Consider first the low-latitude pointing in Figure 2.6. The February to mid-May time period is unavailable because of Sun avoidance restrictions. The Sun-leading region of the sky (October-February) is also relatively inaccessible in two-gyro mode (gold regions) because of the need for fixed-head star tracker (FHST) visibility prior to fine-lock. Thus, in 2007, available orientations are limited to the June through September time frame. A somewhat larger range of orientations is accessible for a very restricted range of dates in late September 2007 and 2008 when the target is located near the anti-Sun direction.

Figure 2.6: Low-Latitude Target Roll Angles Available During Cycle 16

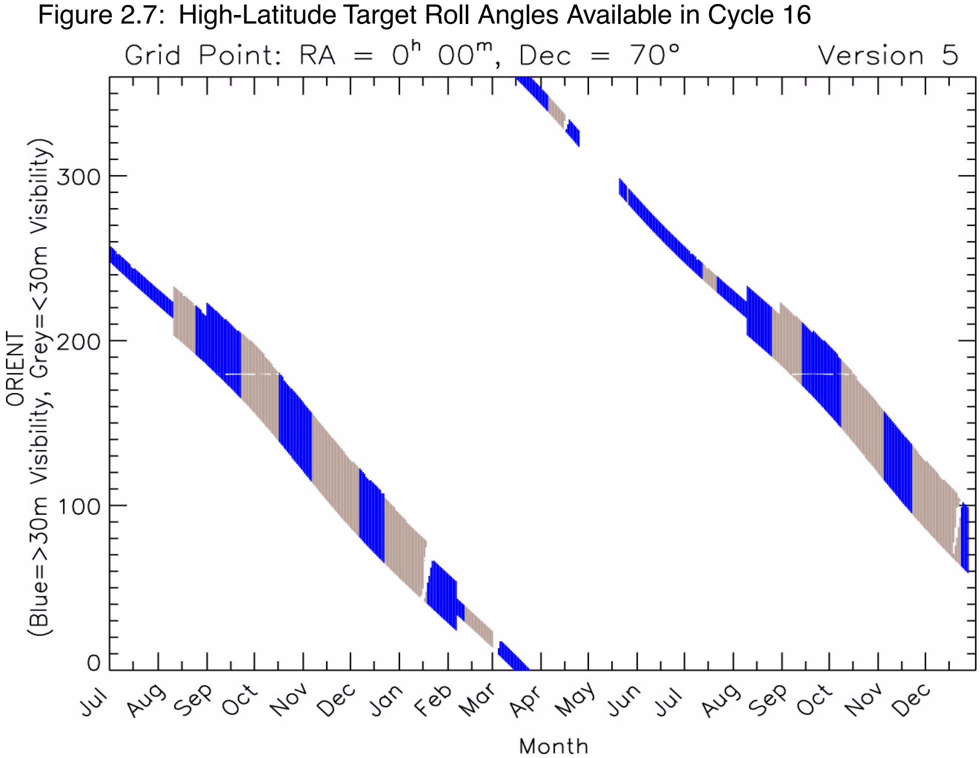


For the high latitude pointing in Figure 2.7, the availability of roll angles in two-gyro mode is broken into several time intervals separated by periods when the object is unobservable. These breaks in availability occur primarily because precession of the HST orbit causes the Earth to block the FHSTs, which are needed for guide star acquisitions.

Table 2.3: A Portion of the Tabular Output for the Data Shown in Figure 2.6

Grid Point: RA = 0^h 00^m, Dec = 0°	
Date	**Available Orientations**
:	:
20-Sep-2007	216.6 - 275.6
21-Sep-2007	216.6 - 275.6
22-Sep-2007	216.6 - 275.6
23-Sep-2007	10.0 - 16.0; 160.0 - 179.0; 180.0 - 346.0
24-Sep-2007	13.0 - 20.0; 164.0 - 179.0; 180.0 - 347.0
25-Sep-2007	39.6 - 46.6
:	:
21-May-2008	241.6 - 251.6
22-May-2008	241.6 - 251.6
23-May-2008	241.6 - 251.6
:	:

Figure 2.7: High-Latitude Target Roll Angles Available in Cycle 16



Plot Example: Target Visibility as a Function of Date

For constrained observations, the orbit visibility may change dramatically throughout the year, unlike unconstrained observations, the visibility cannot be described as a simple function of declination alone (e.g., Table 2.1). The web tool displays the visibility information in graphical form in a plot of target visibility versus time for an 18 month period beginning at the start of Cycle 16 (01-July-2007 to 31-Dec-2008). Plots for the low- and high-latitude sight lines are shown in Figure 2.8 and Figure 2.9. Sample tabular output for Figure 2.8 is shown in Table 2.4. The orbital visibilities in these plots are shown with blue points indicating the maximum visibility available, and by green lines indicating the full range of visibilities for the orientations available. In some instances, the maximum visibility depicted by the blue line may be identical to the minimum visibility in which case there is no green line, just a blue point.

The horizontal black line at 30 minutes in Figure 2.8 and Figure 2.9 indicates the minimum orbital visibility that will be allowed for Phase I proposals in Cycle 16 without special scientific justification. Most observations can be scheduled at times when the orbital visibility exceeds this amount, and those few that cannot will likely have other restrictions that will preclude such observations. For example, in the high-latitude example, the visibility window on 01-October-2007 is only 25 minutes. Therefore, a target at this location in the sky will not be scheduled on this date.

Figure 2.8: Orbital Visibility for a Low-Latitude Target in Cycle 16

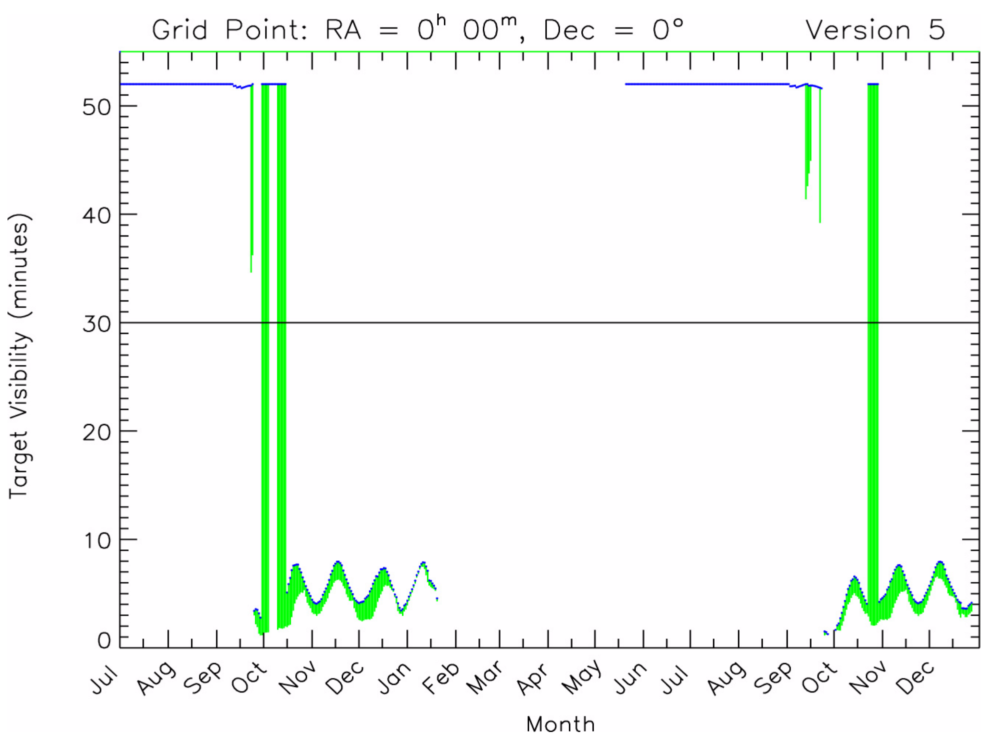
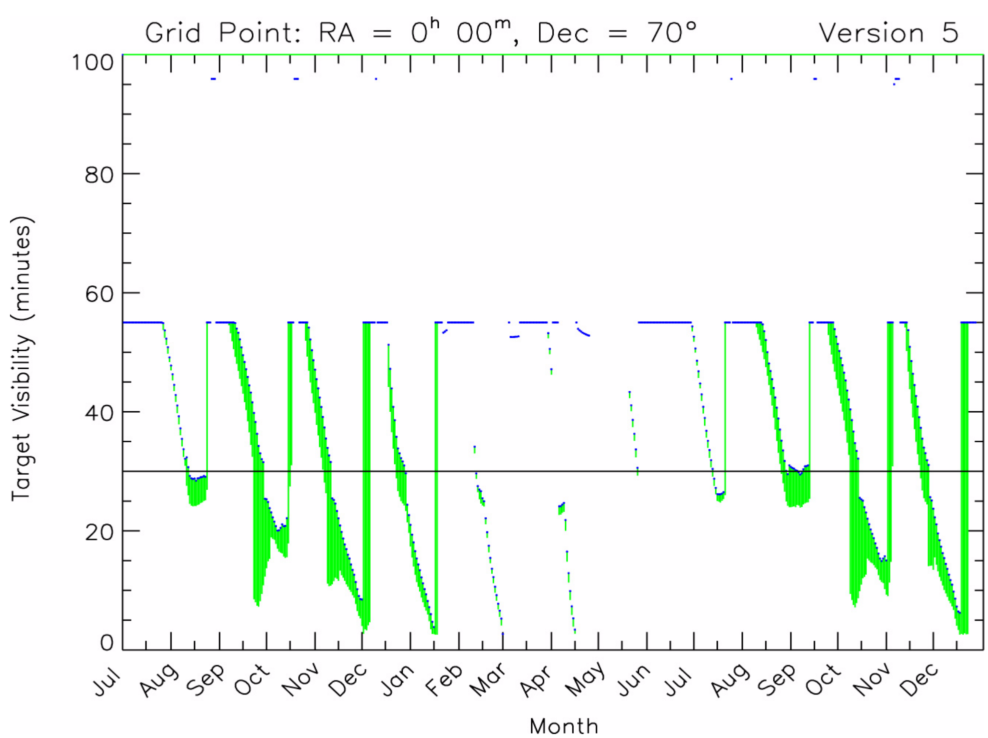


Table 2.4: A Portion of the Tabular Output for the Data Shown in Figure 2.8

Grid Point: RA = 0^h 00^m, Dec = 0°		
Date	Science Time Available (minutes)	
	Two-Gyro (minimum)	Two-Gyro (maximum)
:	:	:
18-Sep-2007	51.7	51.7
19-Sep-2007	51.7	51.7
20-Sep-2007	51.8	51.8
21-Sep-2007	51.8	51.8
22-Sep-2007	51.9	51.9
23-Sep-2007	34.6	51.9
24-Sep-2007	36.2	52.0
25-Sep-2007	3.0	3.4
26-Sep-2007	2.2	3.6
27-Sep-2007	1.9	3.5
:	:	:

Figure 2.9: Orbital Visibility for a High-Latitude Target in Cycle 16



In calculating the orbit visibility period in two-gyro mode for Cycle 16, observers should adopt the maximum visibility estimate indicated by the blue points in the visibility plots unless they have both `ORIENT` and timing restrictions, in which case they need to examine the more detailed visibility plots described in the next section. The HST scheduling system will make every effort to schedule observations when the visibility is optimized.

Detailed Target Visibility Considerations

In some cases it may be necessary to have a more detailed look at the target visibility for various orientations on a particular date to assess whether a highly constrained observation is feasible. The Detailed Visibility Tool on the Two-Gyro Science Mode web page can be used to determine the target visibility. You can enter the target coordinates and the desired date of the observation, and the tool will return a plot and table of the science time available as a function of orientation for the 11 day interval centered on the input date.

Figure 2.10 contains an example of the detailed visibility plot for the high-latitude sight line example on a set of dates centered on 26 September 2007. The resulting visibilities are color coded by date. The information is shown in tabular form in Table 2.5. Observers requiring a specific orientation on a specific date should specify the appropriate visibility indicated by these plots (or tables) in their Phase I proposals.

Figure 2.10: Detailed Visibility Plot for a High-Latitude Target

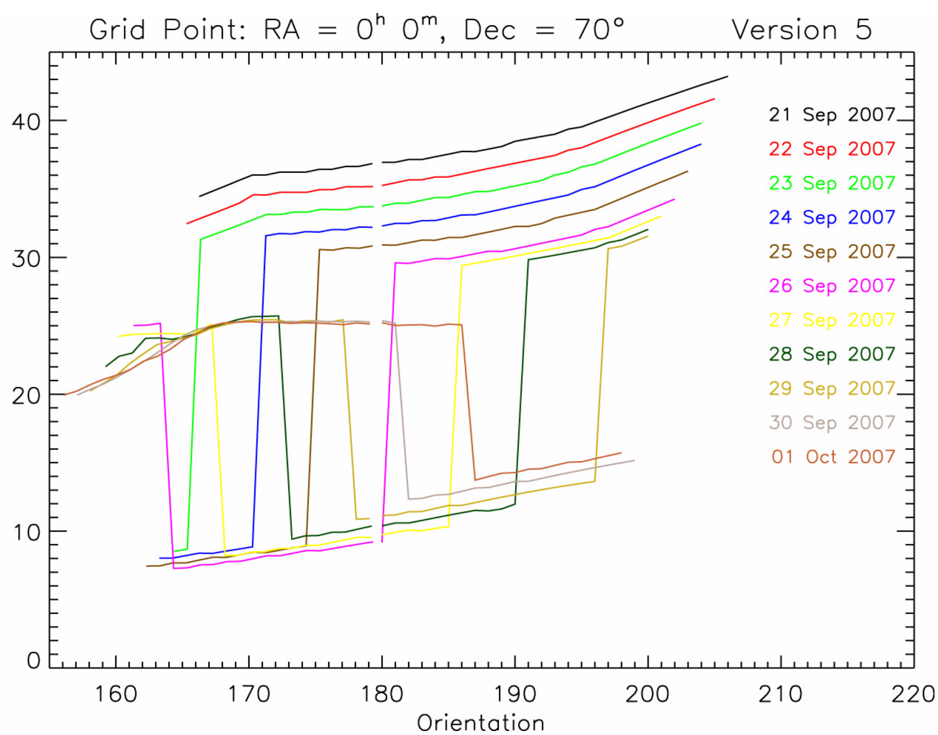


Table 2.5: A portion of the Tabular Output for the Data Shown in Figure 2.10

Orient	Year 2007				Orbital Visibility (minutes)						
	Sep 21	Sep 22	Sep 23	Sep 24	Sep 25	Sep 26	Sep 27	Sep 28	Sep 29	Sep 30	Oct 01
:	:	:	:	:	:	:	:	:	:	:	:
164	0	0	9	8	8	7	24	24	24	24	23
165	0	32	9	8	8	7	24	24	24	24	24
166	34	33	31	8	8	8	25	24	24	25	24
167	35	33	32	8	8	8	25	25	25	25	25
168	35	34	32	9	8	8	8	25	25	25	25
169	36	34	32	9	8	8	8	25	25	25	25
170	36	35	33	9	8	8	8	26	25	25	25
171	36	35	33	32	8	8	8	26	25	25	25
:	:	:	:	:	:	:	:	:	:	:	:

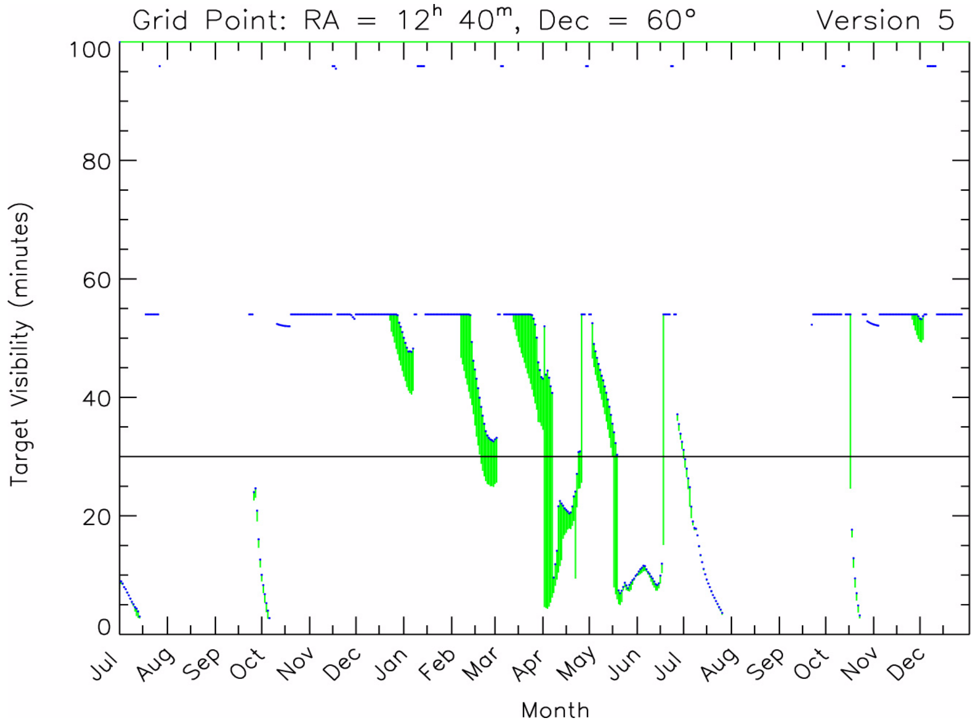
2.2.4 Examples

In this section we provide some examples of how to determine the schedulability and visibility period for different types of observations in two-gyro mode.

`Example 1: Time-series observations of the Hubble Deep Field (HDF) and Hubble Ultra Deep Field (HUDF).`

Observer #1 wants to search for supernovae in the HDF and HUDF by repeating a set of ACS observations every ~45 days for as many consecutive 45-day intervals as possible. The fields are tiled with multiple pointings, each of which has five 400 second integrations designed to fit in a single orbit. The total time required to tile either field is 15 orbits (~1 day). Orientation is not critical, as the field can be tiled in a manner that allows nearly full coverage of the field regardless of orientation. The HDF and HUDF are located at $\alpha = 12^h\ 32^m$, $\delta = +62°18'$ and $\alpha = 3^h\ 32^m$, $\delta = -27°\ 55'$, respectively.

Figure 2.11: Time Available per Orbit for the HDF in Cycle 16



Let's consider first the HDF. Using the on-line tool available at the Two-Gyro Science web site, we examine the scheduling and visibility plots available for the $\alpha = 12^h\ 40^m$, $\delta = 60^\circ$ grid point. The plot of number of available days versus orientation shows that there are many days in Cycle 16 that the HDF is observable in two-gyro mode provided that the orientation is greater than ~180 degrees. Since Observer #1 does not have an orientation constraint, we skip the plot of orientation versus month and proceed directly to the plot of visibility versus month. From this plot (Figure 2.11), we see that good visibility is achievable for this program throughout much of the year.

This program could be conducted with a set of 4 observing opportunities spaced ~45 days apart (e.g., 15-Oct-2007, 01-Dec-2007, 15-Jan-2008, 03-Mar-2008). The science times available per orbit on these dates are listed in Table 2.6. A larger set of observations may be difficult to schedule since the next opportunity in this set (~April 15) has very poor visibility. When dealing with visibilities that change rapidly over the course of a month, flexibility in time series spacing may improve the schedulability. For example, in this case allowing a 54 day separation from March 3 to April 26, instead of the 43 day spacing between March 3 and April 15, would increase the visibility sufficiently to make another epoch of observations possible.

Table 2.6: Two-Gyro Time for the HDF on Selected Dates in Cycle 16

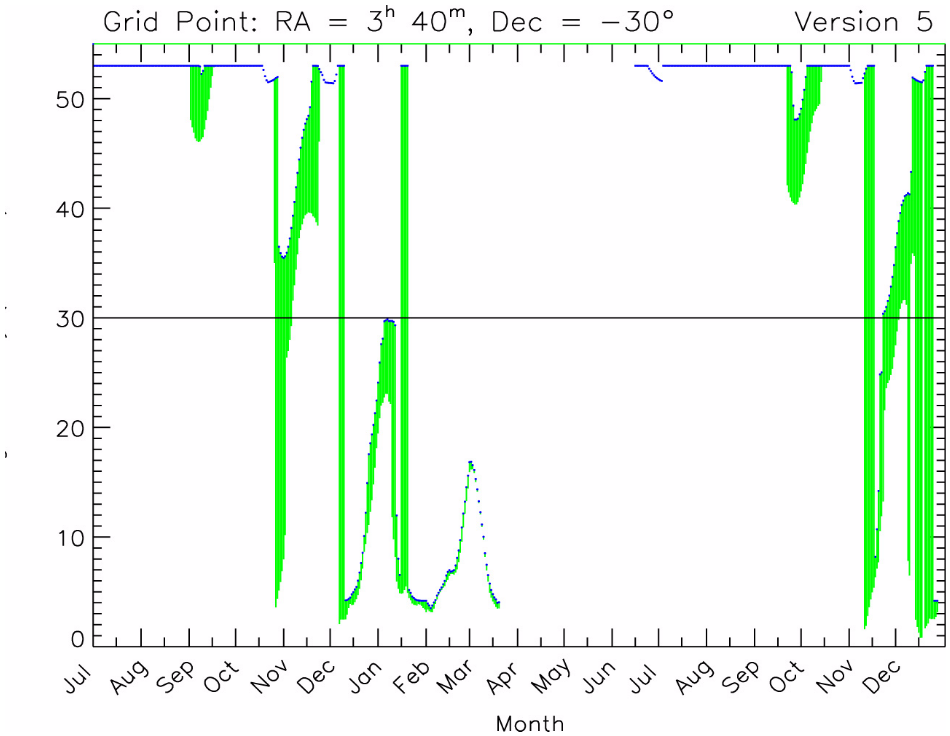
Observation Date	Time per Orbit (minutes)
15-Oct-2007	54
01-Dec-2007	54
14-Jan-2008 15-Jan-2008 16-Jan-2008	96 54 54
01-Mar-2008 02-Mar-2008 03-Mar-2008	33 33 54
15-Apr-2007 16-Apr-2007 17-Apr-2007	21 21 21

Now consider the HUDF. Using the on-line tool available at the Two-Gyro Science web site, we examine the scheduling and visibility plots available for the $\alpha = 3^h\ 40^m$, $\delta = -30^\circ$ grid point. The possibilities for scheduling a series of observations with a spacing of 45 days is more limited due to the gap from February 2008 to June 2008. Starting the series early in the cycle is the best way to obtain four observing opportunities.

Table 2.7: Two-Gyro Time for the HUDF on Selected Dates in Cycle 16

Observation Date	Time per Orbit (minutes)
05-Jul-2007	53
01-Sep-2007	53
15-Oct-2007	53
01-Dec-2007	51

Figure 2.12: Time Available per Orbit for the HUDF in Cycle 16



`Example 2: Time-series light curve observations of a supernova found in Example 1.`

Observer #1 finds a supernova in the HDF using the experiment outlined in Example 1 and wants to obtain the light curve of the supernova by obtaining photometric images of the supernova and surrounding field once a week for 7 weeks. The supernova was discovered after the fourth set of observations was obtained on 03-March-2008.

Using the visibility versus month plot generated for Example 1, Observer #1 notes that the orbital visibilities for the HDF and surrounding areas are good on march 10 and 17 (54 minutes), as well as March 24 and 31 (54 and 43 min, respectively) and April 7 (41 min). However, by April 14 the visibility has dropped to 21 minutes, and on April 21 it is only 23 minutes. Thus, it is not possible to follow the supernova light curve throughout the entire 7-week period as hoped.

`Example 3: An orientation-constrained observation of the Vela supernova remnant.`

Observer #3 wants to take an ACS image of a portion of the Vela supernova remnant near the position of the star HD 72089 ($\alpha = 08^h\ 29^m$, $\delta = -45^\circ\ 33'$). A roll angle of 70±5 degrees must be used to keep the bright star off the detector. A second observation to observe a different part of the remnant requires an orientation 90±5 degrees from the first observation.

Entering the coordinates of HD 72089 into the scheduling tool on the web yields the following plots of the number of days each orientation is available (Figure 2.13) and orientation versus month (Figure 2.14) for the nearby position at $\alpha = 8^h\ 20^m$, $\delta = -45^\circ$. It is apparent from these plots that neither an orientation of 70 degrees nor an orientation of 90 degrees is achievable in two-gyro mode at any time in Cycle 16.

Realizing that the planned orientations are not viable, Observer #3 checks the availability of orientations 180 degrees from those originally envisioned. The inverse orientations at 250 degrees and 340 degrees are accessible near 01-October-2007 and 01-January-2008, respectively. Therefore, this observation is feasible in two-gyro mode as long as the requested orientations are changed to 250±5 degrees and 340±5 degrees. The availability of allowable orientations must be described appropriately in the Phase I proposal.

Figure 2.13: Cycle 16 Orientation Availability in the Direction of the Vela SNR

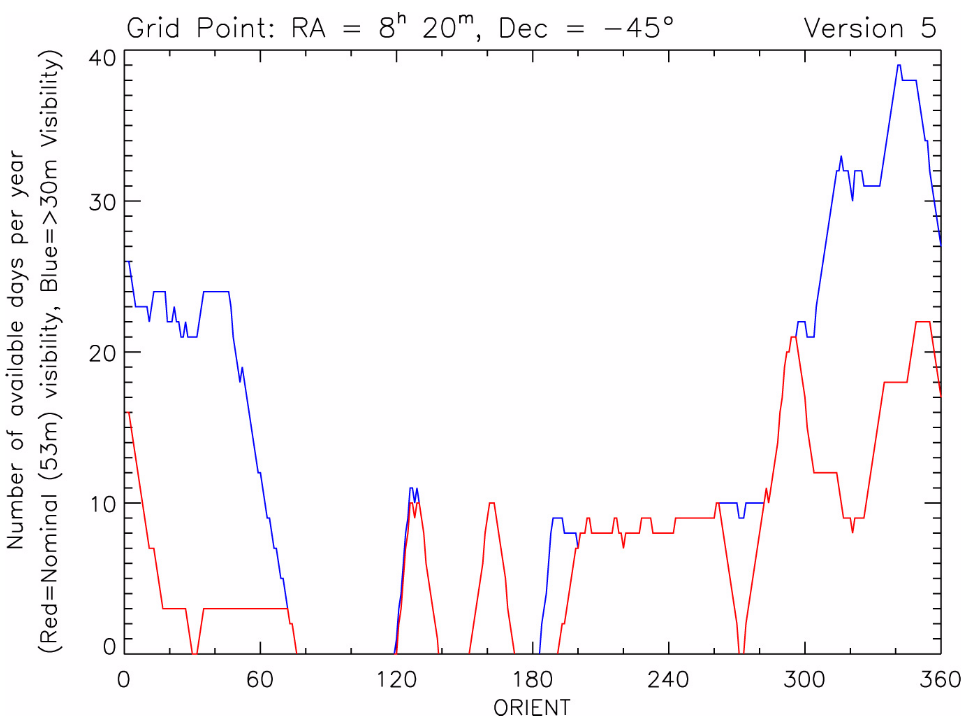
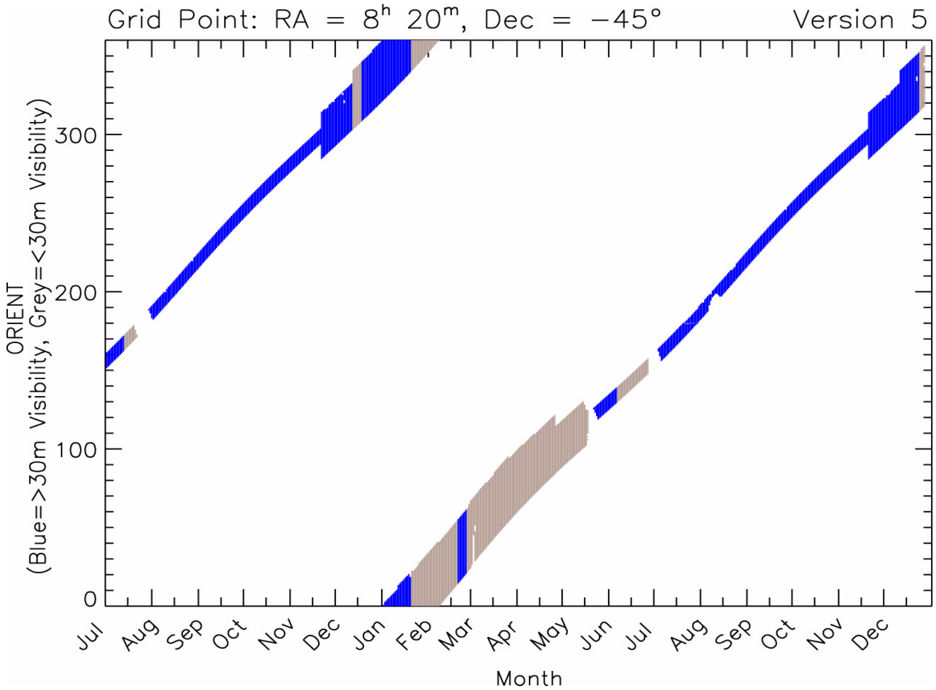


Figure 2.14: Cycle 16 Orientation Angles Versus Month Toward the Vela SNR



2.3 Verifying Scheduling Constraints for Phase I

The Astronomer's Proposal Tool (APT) package contains software to check the schedulability of targets in Phase I proposal forms. When filling out the APT form for their Phase I proposals, proposers will be asked to verify the availability of their targets in two-gyro mode. Proposers should perform this check after they have entered their observation information based upon the tables and plots discussed in the previous sections of this chapter.

2.4 Two-Gyro Orbit Calculations for Phase I

The visibility period for two-gyro observations should make use of the two-gyro visibility periods from the plots and tables described in this chapter. The tools for creating these plots and tables are available on the Two-Gyro Science Mode web site. Exposure times for two-gyro observations should be calculated with the appropriate two-gyro exposure time calculators (ETCs) for each instrument. In most cases, these are the same ETCs as were used for three-gyro mode since the instrument performance in both cases is nearly indistinguishable. Links to these ETCs can be found on the main web page for each instrument.

2.5 Continuous Viewing Zones

The continuous viewing zones (CVZs) are regions of the sky where HST can observe without interruptions caused by target occultation by the Earth. These zones are approximately 24 degrees in size centered on the orbital poles, which are 28.5 degrees from the celestial poles. Thus, targets located in declination bands near ±61.5 degrees may be in the CVZ at some time during the 56-day HST orbital precession cycle. The CVZ interval duration depends upon the telescope orbit, target position, and constraints imposed by Sun and Earth limb avoidance. South Atlantic Anomaly crossings limit the uninterrupted visibility of any target to no more than 5-6 orbits (see Section 2.3.2 in the *HST Primer*).

The CVZs in two-gyro mode will be the same size as those in three-gyro mode, but the durations may be shorter because of more restrictive pointing constraints. To determine whether constrained two-gyro observations qualify for CVZ time, observers should consult the visibility tables and plots, like those discussed above. Only those observations for which the orbital visibility is 96 minutes should be considered CVZ candidates.

2.6 Moving Targets

There is no significant impact of two-gyro operations on moving target observations other than that gyro-only tracking and guide star handoffs are not available in two-gyro mode. Proposers wanting to observe moving targets should consult the Two-Gyro Science Mode web page for updates, which will be posted as further information about observing moving targets in two-gyro mode becomes available.