WFC3 Cycle 21 Calibration Plan

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WFC3 Usage

WFC3 is extremely successful because of its:

- panchromatic capabilities (wavelength range from 200nm to 1700nm);
- multiple observing modes (imaging, spectroscopy, variety of readout modes, 80 different filters: narrow, medium, broadband, and grisms).
- Both channels continue to be very popular.

PERCENTAGE OF EXPOSURES FOR WFC3 CHANNEL				
	UVIS	IR	IMAGING	SPECTROSCOPY
Cycle 17	49%	51%	92%	8%
Cycle 18	22%	78%	40%	60%
Cycle 19	44%	56%	77%	23%
Cycle 20	36%	64%	80%	20%
Cycle 21	33%	67%	59%	41%

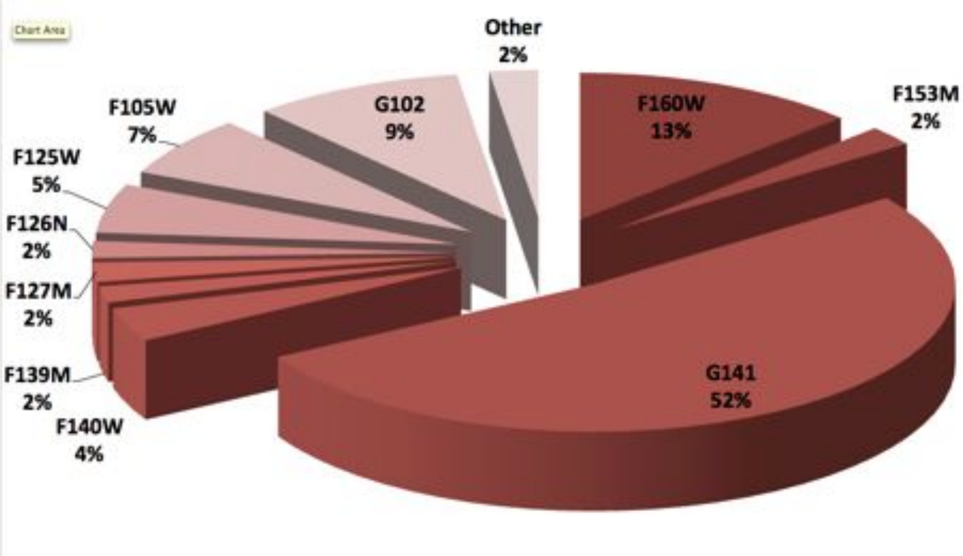
WFC3 Usage with time

HST Cycle	GO Programs* % of HST orbits	Calibration** # External orbits	Calibration** # Internal orbits
CY17	46.1%	256	>2000
CY18	41.9%	134	1719
CY19	48.6%	125	1497
CY20	56.3%	83	1833
CY21	53.6%	98	1907

*MCTs, SNAPs and Frontier Fields are not included
**Delta Calibration Programs are not included

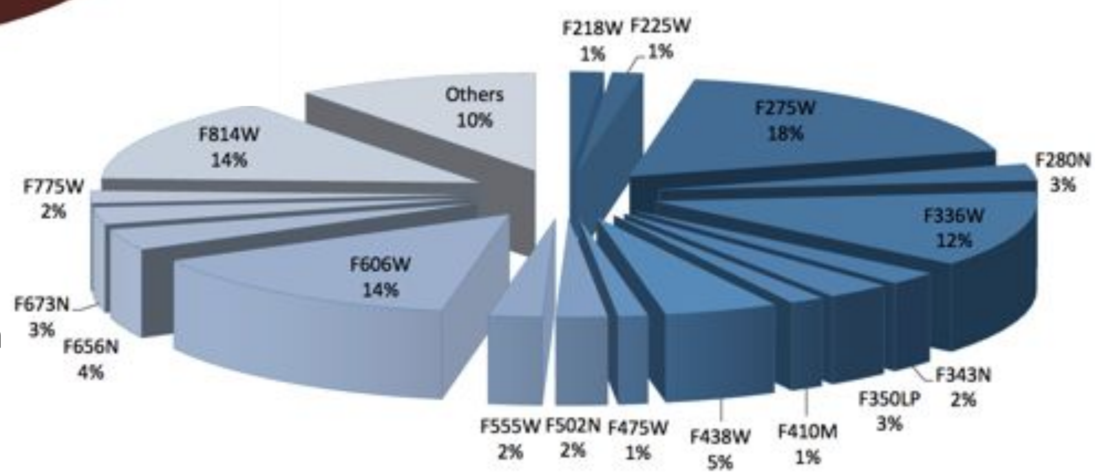
Filter Usage

IR – Percentage of Exposures



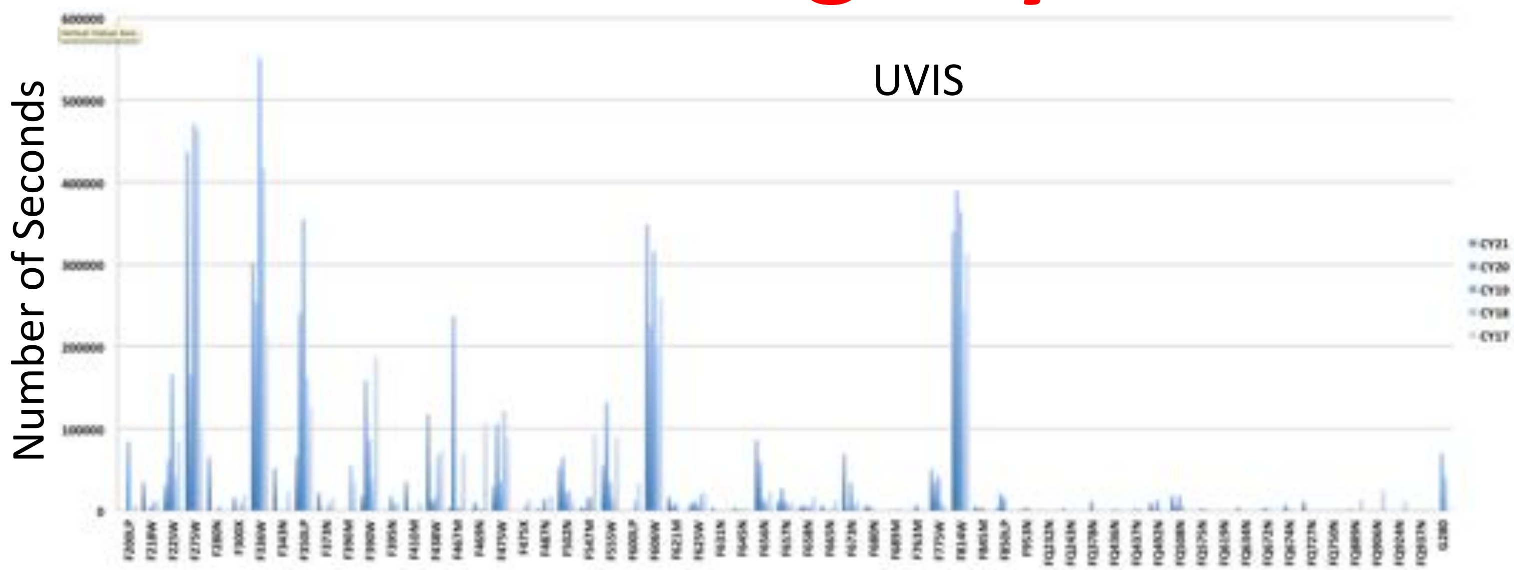
- ~60% of the IR observations use GRISMS
- 14 out of the 15 IR filters are used in CY21
- 35% of the exposures uses spatial scan

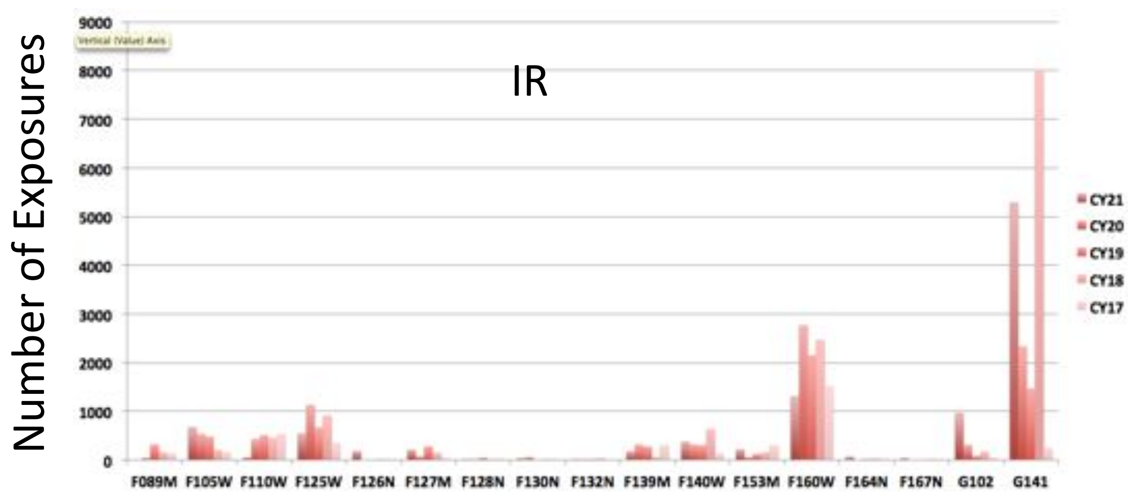
- 44% of UVIS time is used to observe in the near UV
- 48% of UVIS observations use post-flash
- 44 out of the 62 UVIS filters are used in CY21
- 2.5% of UVIS time is for spatial scan



UVIS – Percentage of Time

Filter Usage Cycles 17-21





Proposed Program

Program Title	Ext. Orbits	Int. Orbits		Program Title	Ext. Orbits	Int. Orbits
UVIS anneal	0	85		IR persistence model tests*	8	8
UVIS bowtie monitor*	0	243		Trapping mitigation in spatial scan observations of exosolar planets*	15	0
UVIS CCD daily monitor*	0	644		WFC3 contamination & stability monitor	10	0
UVIS CCD un-flashed monitor*	0	140		WFC3 UVIS & IR photometry*	18	0
UVIS post-flash monitor	0	60		IR Grism: cross checking sensitivity function of hot and cool star*	1	0
UVIS CCD gain stability	0	18		UVIS Grism: flux calibration*	2	0
IR dark monitor	0	95		UVIS Grism: wavelengths calibration & stability*	2	0
IR linearity monitor	3	9		IR Grisms: flux calibration*	4	0
IR gain monitor	0	16		IR Grisms: wavelengths calibration & stability*	4	0
UVIS CTI monitor (EPER)	0	12		IR Grisms sky characterization*	2	20
UVIS CTE monitor (star cluster)*	6	0		Recalibration of the IR Grism wavelength ZPs*	2	0
CTE characterization with post-flashed darks*	0	15		UV flats via spatial scan*	8	0
Characterization of the charge-level dependence of CTE losses*	0	13		UV flat field validation*	4	0
Characterization of UVIS traps with CI*	0	72		CCD anomalous QE pixels*	0	24
UVIS & IR geometric distortion	6	0		UVIS internal flats	0	15
High precision astrometry*	3	0		IR internal flats	0	18
				CMS monitor with earth flats*	0	400

CY21 Total external orbits=98; Total internal orbits=1907

CY20 Approved Program

Program Title	Ext. Orbits	Int. Orbits		Program Title	Ext. Orbits	Int. Orbits
13071-UVIS Anneal	0	107		13088-WFC3 contamination & stability monitor	11	0
13072-UVIS Bowtie monitor	0	130		13089-WFC3 UVIS & IR photometry	16	0
13073-4-5-6-UVIS CCD daily monitor	0	805		13090-UVIS Grism: Flux calibration	2	0
13168-UVIS CCD gain stability	0	10		13091-UVIS Grism: Wavelength calibration and stability	2	0
13078-UVIS post flash monitor	0	64		13092-IR Grism: Flux/trace calibration and stability	2	0
13077-IR Dark monitor	0	120		13093-IR Grism: Wavelength calibration and stability	2	0
13079-IR linearity monitor	3	9		13094-IR Grism -1 Order calibration	7	0
130080-IR gain monitor	0	16		13095-UV L-Flats via Spatial Scans	8	0
13081-Guard Darks for MCT Programs	0	80		13096-UVIS Flat Field Validation	3	0
13082-UVIS CTI monitor (EPER)	0	24		13169-CCD Anomalous QE pixels	0	24
13083-UVIS CTE monitor (star cluster)	9	0		13097-UVIS Internal Flats	0	20
13084-Characterization of UVIS traps with CI	0	122		13098-IR Internal Flats	0	30
13085-Line 10 CI bias to support a GO program	0	60		13099-IR Earth Flats	0	100
13086-IR persistence behaviors as a function of saturation time	0	72		13100-UVIS & IR Geometric Distortion Calibration	5	0
13087-IR persistence model tests	0	40		13101-High Precision Astrometry	13	0

Total external orbits = 83

Total internal orbits = 1833

Supplemental orbits= 170 internal

UVIS Detectors

To monitor the health of the UVIS channel we ask for 1190 internal orbits divided as follow:

1. 85 internal orbits (the cadence has been synchronized with the other HST instruments) to perform an anneal every month
   - CSM usage reduced by dropping IR darks.

2.* 243 internal orbits to mitigate the hysteresis (bowtie) effect via a series of unsaturated and saturated int-flats.
   - Frequency increased to allow better scheduling with fewer CMS movements.

3.* 644 internals to perform a daily monitoring of the CCDs behavior using a series of dark and biases.
   - Provide updated darks and hot pixel maps

4.* 140 internals to assess how well post-flash is mitigating CTE with time using a series of unflashed darks

5. 60 internal orbits to monitor the stability of the post-flash LED with time.
6. 18 internal orbits to verify the stability of the gain in the 4 UVIS quadrants for all the available binning modes by taking a series of internal flats over a range of integration times.

WFC3/UVIS Anneal

Number of external orbits: 0

Number of internal orbits: 85

Goals: Perform regular anneal procedures in order to repair hot pixels and acquire internal images to assess the procedure's effectiveness. The internal exposures are also used to produce reference files for the calibration pipeline.

Description of the observations: Anneals are performed every 28 days, a cadence which optimally interleaves the WFC3 procedure with those from other instruments (one instrument/week). Internal biases as well as darks are taken before and after each procedure to provide a check of bias level, read noise, global dark current, and hot pixel population. A bowtie visit is acquired immediately after each anneal to provide a 'fixing' image and verify that any hysteresis has been successfully quenched. Since April 2012, the WFC3 anneals have been performed keeping the IR detector cold (IRTEMP=COLD). In Cycle 21, one iteration <u>may</u> be executed according to the original anneal procedure commanding which includes a partial warming of the IR detector; in that event, one post-anneal IR dark will be needed.

Orbits required: 85 total = 14 * 6 + 1

-- 14 iterations provide seamless continuation of the cadence across cycle boundaries

-- 6 orbits are needed per iteration (2 orbits bias/dark before and 2 orbits bias/dark after each anneal, 1 "orbit" for the anneal itself, 1 orbit for the post-anneal bowtie visit)

-- 1 orbit for one IR dark to be taken after one iteration using the original anneal procedure which partially warms the IR detector.

WFC3/UVIS Bowtie Monitor

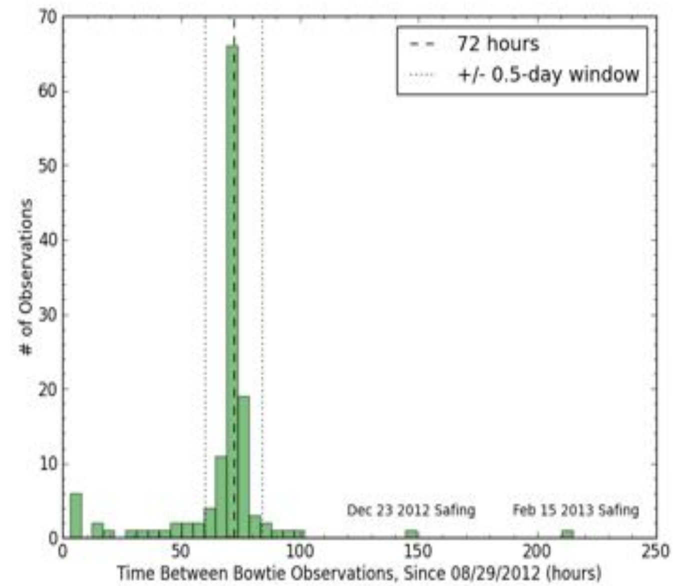
Number of external orbits: 0

Number of internal orbits: 243

Goals: Monitor and neutralize hysteresis in the WFC3/UVIS detector.

Description of the observations: Each bowtie observation consists of a single continuous visit containing three internal flatfield exposures: (1) an unsaturated image as a check for the presence of hysteresis, (2) a saturated 'QE pinning' exposure used to neutralize QE offsets, and (3) an additional unsaturated image to provide an estimate of the QE offset removal efficiency. All images are 3X3 binned as to minimize data volume and overhead; each visit requires ~360 seconds of telescope time.

One orbit every three days is needed for the first two months of the cycle (20 orbits). After two months, the observation window for each orbit is extended from +/-0.5 days to +/- 0.75 days as to provide an ease in scheduling under new CSM movement constraints. As a result, 5 orbits per week are required to fill in possible 3+ day gaps between bowtie observations. Thus, a total of (5 orbits/week * 43 weeks =) 215 orbits will be needed spanning months 3-12. An additional 8 orbits are used to serve as on-hold contingency visits (e.g., for recovery from a safing event), increasing the total orbits to 20 + 215 + 8 = 243. In the event that additional scheduling is not needed during months 3-12, the total number of orbits drops to as low as 128 (20 + 100 + 8).



A histogram showing the time between bowtie observations over the past year, in hours. Outliers exceeding the +0.5 window are due to an occasional bowtie visit occurring early during one window and late during the subsequent window, as well as dropped bowtie visits from safing events. Outliers that occur prior to the -0.5 day window are due to close time proximity of UVIS anneals (which themselves contain bowtie visits).

WFC3/UVIS CCD Daily Monitor

Number of external orbits: 0 **Number of internal orbits:** 644

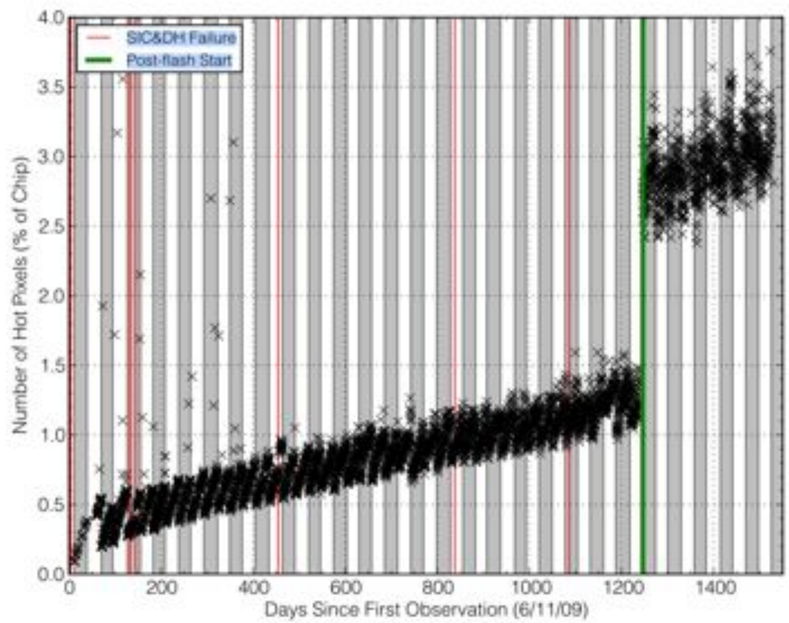
Goals: Monitor the behavior of the UVIS CCDs with a daily set of bias and dark frames. These data will be used to generate bias and dark reference files for CDBS, which are used to calibrate all WFC3/UVIS images.

Description of the observations: The internals are acquired using a pattern of single-orbit visits repeated every 4 days (see below). All darks are 900 sec in duration and all exposures will be post-flashed. A small number of un-flashed internals are requested in a separate proposal.

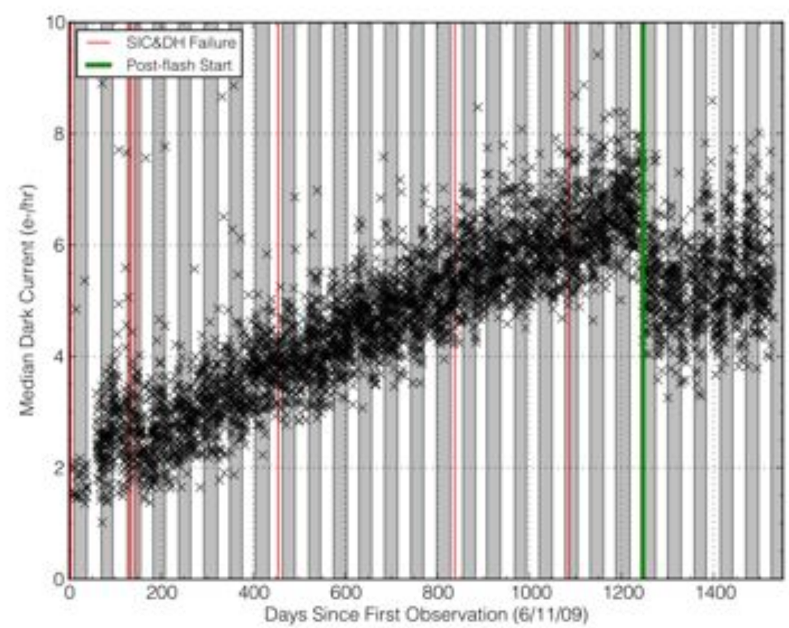
Day1 – 2 visits: one with 2 biases +1 dark, one with 2 darks
Day2 – 2 visits, each with 2 darks
Day3 – 1 visit with 2 darks
Day4 – 2 visits, each with 2 darks

Orbits needed: 644 = 92 * 7 (= 92 iterations of the 4-day pattern)

Four separate proposal numbers to cover this single program would facilitate APT processing.



This plot shows the hot pixel growth between anneals for WFC3/UVIS. The number of hot pixels are plotted as a function of time since the installation of WFC3 on HST, where red lines represent SIC&DH failures, when WFC3 was safed, and the grey/white regions represent anneal cycles. Note that the implementation of post-flash occurred on day 1246.



Shows the dark current vs. time for WFC3/UVIS. The red lines represent SIC&DH failures, when WFC3 was safed, and the grey/white regions represent anneal cycles. Note that the implementation of post-flash occurred on day 1246.

WFC3/UVIS CCD Un-flashed Monitor

Number of external orbits: 0

Number of internal orbits: 140

Goals: Monitor the temporal changes in CTE losses and the efficacy of the post-flash mode.

Description of the observations: The large set of internals taken as part of the daily monitor are all post-flashed. However, a small number of un-flashed internals are required to monitor the changes in CTE losses over time. The un-flashed internals, in conjunction with the post-flashed internals, will allow for an assessment of how well the post-flash is mitigating those losses. Ten full-frame, four-amp un-flashed 900 sec darks are taken every month. To facilitate scheduling, short visits of only 1 dark each are used rather than the normal 2 darks/orbit; the darks are grouped around the anneal iterations: 5 darks the week before and 5 darks the week after each procedure.

Orbits needed: 140 (= 10 darks x 14 anneal iterations)

WFC3/UVIS Post-flash LED Monitor

Number of external orbits: 0

Number of internal orbits: 60

Goals: The flux and illumination pattern of the post-flash LED are monitored over time. The data are also used to generate post-flash reference files for the calibration pipeline.

Description of the observations: Most observers with low–background data are now making use of the post-flash (PF) mode in WFC3/UVIS. In the previous cycle, sufficient data were obtained to establish a baseline of the brightness and light distribution of the LEDs and produce the first calibration files. In this cycle, we propose monthly monitoring of the lamp characteristics plus sufficient orbits to allow a new generation of post-flash CDBS reference files to be created.

Each iteration of the monitor needs 3 orbits: two are used to obtain pairs of high S/N flashed full-frames for both shutter blades (pattern check) and one orbit for 1K x 1K subarrays taken at a variety of post-flash levels (brightness check). For new reference files, 12 orbits are needed; we request an extra set of 12 orbits in the event the LED illumination pattern changes more rapidly than anticipated. If it should remain stable, these last 12 orbits would not be needed.

Orbits needed: 60 = 12 x 3 +12 +12 on-hold

UVIS Gain Stability

Number of external orbits: 0

Number of internal orbits: 18

Goals: Monitor the absolute gain for the nominal detector readout.

Description of the observations: Observations consist of 8 pairs of full-frame binned (BIN=2 and BIN=3) and unbinned internal calibration subsystem flat fields at nominal gain. Images are taken with a variety of exposure times to provide a mean-variance measurement of the gain. Two epochs, 9 orbits each, are requested, to be taken ~6 months apart. Six of these orbits will be for sampling the unbinned mode, an orbit more than previous cycles, so that we may increase the sampling at lower signal levels. The additional data in the linear region of the mean-variance plot will improve the gain measurement.

IR Detector

To monitor the health of the IR channel we ask for 120 internal and 3 external orbits, divided as follow:

1. 95 internal orbits to obtain IR dark calibration files. The number of orbits is dictated by the observing modes requested by GOs.
2. 3 external (low and high signal ramps of 47 Tuc) and 9 internal orbits (saturated internal flats) to monitor the IR non-linearity and update the calibration reference file.
3. 16 internal orbits to verify the stability of the IR channel gain via a series of lamp flats. Different orbits are required to avoid persistence effects.

IR Dark Monitor

Number of External Orbits: 0 **Number of Internal Orbits:** 95

Goals:

- Obtain IR dark ramps necessary to support Cycle 21 Observations, with a focus on maximizing the signal to noise ratio for superdarks of the most popular modes.
- Obtain IR dark ramps necessary to continue the monitoring of dark current, zeroth read level, and bad pixels (hot, unstable, or dead).

Description of the Observations:

The IR dark current has remained effectively unchanged since launch (Hilbert & Petro, WFC3 ISR 2012-11). This stability has allowed us to reduce the number of requested internal orbits by ~20% compared to the cycle 20 IR dark monitor (and continues the downward trend in orbit requests for the fourth straight cycle). The dark current will still be monitored across all aperture size/ sample sequence combinations used by Cycle 21 observers, just at a reduced cadence. The additional dark ramps acquired will be used to improve the SNR of the CDBS pipeline darks for the most popular modes. In addition, the longest observations (SPARS200/FF) will continue to be used to monitor bad pixels and provide updates to the bad pixel mask.

WFC3/IR Linearity Monitor

Number of external orbits: 3

Number of internal orbits: 9

Goals: Monitor the signal non-linearity of the IR channel as well as update the IR channel non-linearity calibration reference file.

Description of the observations:
Internal orbits - Each internal orbit will be used to acquire one intflat exposure up to saturation in order to provide a pixel-to-pixel map of the non-linearity of the detector. To manage persistence, each intflat is preceded and followed by a dark current exposure. A short, low signal intflat also precedes each intflat, to ensure the tungsten lamp has reached a steady state for the linearity observation. Each dark current exposure will be collected following a new rule specifying that the CSM remain in the orientation used for the preceding exposure. This will help to limit the total number of CSM moves related to this proposal.

External orbits - During the external orbits, low and high-signal ramps of 47 Tuc are acquired, to evaluate point source non-linearity behavior. Observation times are optimized for stars in the magnitude range V=17-22. In the low-signal ramps, stars V=17 just reach full well, while those at V=22 will have S/N~30. In the high-signal ramps, V=20 stars will be saturated, and V=22 stars will have S/N ~130. At these signal levels 47 Tuc provides many sources for the analysis of the non-linearity, from the low end at V=22, to the bright end, where some source will have signals well over full-well. This observing strategy is modeled after the non-linearity test performed on ACS (Gilliland, ACS ISR 2004-01). This program is a continuation of program 13079.

WFC3/IR Gain Monitor

Number of external orbits: 0

Number of internal orbits: 16

Goals: Measure gain in the IR channel and compare to values from previous cycles.

Description of the observations: The 16 orbits will be used to acquire 16 internal flats for use in computing the detector gain via the mean-variance technique. To manage persistence effects, the gain intflats are not taken back-to-back, but in their own orbits. Furthermore, each gain intflat is preceded by a dark ramp and, to ensure the internal lamp is at full output, a short low S/N narrowband exposure. The gain intflats are acquired at ~1/2 full---well to minimize non-linearity corrections. Each dark current exposure will be collected following a new rule specifying that the CSM remain in the orientation used for the preceding exposure. This will help to limit the total number of CSM moves related to this proposal.
This is a continuation of program 13080.

CTE Characterization and Calibration

This part of the calibration program requires 6 external and 112 internal orbits.
As in Cycle 20, GOs can mitigate CTI effects using post-flash. Anderson's CTE correction algorithm will be implemented in CALWF3 during FY2014. To support these efforts we ask:

1. 12 internal orbits will be used for a every other month measurement of the CTE via Extended Pixel Edge Response (EPER).
2.* 6 external orbits will be used to observe stellar fields characterized by different crowding and background (2 fields in 47 Tuc and 1 in NGC 6791) to calibrate the photometric and astrometric CTI corrections.
3.* 15 internal orbits of short and long darks will be used to confirm the predictions of the Anderson's algorithm.
4.* 13 internal orbits with post-flashed charge injected darks will be used to characterize the response of charge traps at different background levels
5* 72 internal orbits with charge-injected bias to monitor the length of the CTE trails. This information will be used as an input for the Anderson's algorithm.

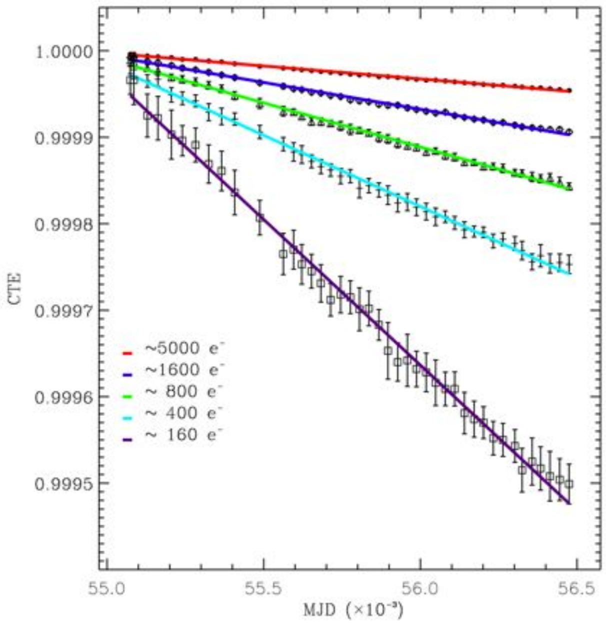
WFC3/UVIS CTI Monitor (EPER)

Number of External Orbits: 0

Number of Internal Orbits: 12

Goals:
(1) Measure the WFC3/UVIS CCD Charge Transfer Inefficiency (CTI) using the Extended Pixel Edge Response (EPER) method.
(2) Assess the CTE losses over time in a continuation of the multi-cycle CTE monitor program.

Description of the Observations: 12 internal orbits, grouped in pairs of visits, are used to assess the profiles of excess charge in the extended pixel region of the special EPER readout format and monitor the CTI of WFC3/UVIS. Each visit-pair obtains internal lamp flatfields at a variety of illumination levels as well as two short dark exposures to be used as a bias measurement. A visit-pair is taken approximately every 8 weeks over the span of a year.



CTE as a function of time for a range of signal levels spanning August 2009 through July 2013. CTE continues to decline linearly and decreases most rapidly for the lowest signal level of 160 e-.

UVIS External CTE Monitor: Star Clusters

Number of external orbits: 6

Number of internal orbits: 0

Goals: Monitor CTE degradation as a function of epoch and source/observation parameters; calibrate photometric and astrometric corrections, provide data to test and monitor the Anderson pixel-based CTE correction model for WFC3/UVIS

Description of the observations: Consistent continuation of the previous external CTE monitoring programs; we keep the modification adopted in Cycle 20, using post-flash to sample background levels and monitor the post-flash mode as an instrument for CTE mitigation.

Exposures of NGC 6791 and NGC 104 (47 Tuc) in F502N (zero background) to continue monitoring of maximum CTE in different field densities. Long exposures, dithered by 2000 pixels in detector Y, to measure absolute CTE. Few short exposures as fillers at ends of orbits for long-short flux ratio tests.
While we had hitherto observed 3 epochs per Cycle, we now reduce the frequency to 2 epochs per Cycle. The CTE evolution has been found to be slow and smooth enough to warrant this reduction in use of external orbits.
Orbit use: 1 orbit for NGC 6791, 2 for 47 Tuc (5 non-zero background levels), -> 3 orbits per epoch, times 2 epochs: 6 orbits total.
Additional, special calibrations taken in Cycle 19 (CAL/WFC3 12692) were exploratory and will not be repeated in the current Cycle 21.

Characterization of UVIS traps with Post-Flashed Darks

Number of external orbits: 0

Number of internal orbits: 15

Goals: This program will use short and long postflashed darks to construct an up-to-date calibration of the WFC3/UVIS CTE MODEL. When a similar set of these images was taken in MID-2012, there were not as many warm pixels as there are now. Furthermore, this program will explore a finer spacing of backgrounds to help us understand exactly what happens above the "sweet-spot" background of 12 electrons. Once the model is recalibrated using this data set (which should be taken in early 2014), we can feel confident in making the pixel-based correction part of the pipeline.

Description of the observations: We will take short 100s darks with PF levels of: 0, 1, 2, 3, 4, 5, 6, 8, 10, 12, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 125, and 150 --- 30 levels in all. We will also take 1000s darks (or longer) with a PF level of 100. We should be able to take two shorts and one deep in each orbit, so it should take a total of 15 orbits. This will give us 15 long darks, which can be averaged together.

It would be best if this program could be scheduled to be executed over the course of only a few days, to avoid large changes in the darks.

Characterization of the Charge-Level Dependence of CTE Losses

Number of external orbits: 0

Number of internal orbits: 13

Goals: This program will use charge-injection to explore CTE losses as a function of position and charge-level across the detector. The UVIS pixel-based CTE-reconstruction model characterizes average CTE losses across the detector in terms of the number of traps in each column that affect each Nth electron, but the traps are not uniformly distributed across the detector. In addition, the traps are not all the same: some affect the first electron, some the second, etc, depending on exactly where they lie within the pixel relative to the resting or shuffling pixel cloud.
CI images with no background allow us to roughly identify where are the traps. Adding increasing levels of post-flash will allow us to characterize where are the low- and the high-electron-grabbing traps.

Description of the observations: We will acquire 9 CI images with no background (the baseline), and then we will collect CI images with an array of background values (either from the post-flash or by tungsten lamps): 1, 2, 3, 4, 5, 6, 8, 10, 12, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 125, and 150, 250, 400, 650, 1000, 1500, 1500, 2500, 4000, 6500, 10000, 15000, 25000, 35000, and 50000, for a total amounts of 52 internal exposures, corresponding to 13 orbits. Ideally the data should be acquired over the period of ~1 month.

Characterization of UVIS traps with Charge-Injection

Number of external orbits: 0

Number of internal orbits: 72

Goals: This program is designed to monitor the UVIS trap growth via charge-injected biases

Description of the observations: We request 72 internal orbits to monitor the growth of UVIS traps. Line 25 charge-injected biases will be acquire every 5 days. This is a continuation of programs CY19-12784 and CY20-13084. In previous cycles the program was also used to support GO proposals that were using charge-injected observations. In the past Cycles line 17 charge-injected biases were also collected to support GO observations. Since in CY21 there are no programs that will use charge-injection, we are not collecting these biases.

Astrometric Calibration

We request 9 external orbits to:

1. Monitor the stability of the geometric distortion for both the UVIS and IR channels - 6 orbits.

2.* Use spatial scans to increase our knowledge of the internal distortions of WFC3/UVIS, and its time dependency – 3 orbits.

WFC3/UVIS and IR Geometric Distortion Corrections and its stability

Number of external orbits: 6

Number of internal orbits: 0

Goals: The observations of the standard astrometric catalog in the field of globular cluster Omega Cen will be used to evaluate the time dependency of UVIS and IR geometric distortion. The observations of the same field from the previous cycles have show that the WFC3 geometric distortion appears to be stable and there is no evidence of a secular changes on the two-and-half – years time scale. However, during each interval of the orbital target visibility, there is a linear trend of the UVIS and IR X & Y axes skew at the level of +/-2 and +/-7 mas, respectively (Kozhurina-Platais et.al 2012, WFC3-ISR-2012-03). Thus, the observations of Omega Cen through UVIS F606W filter and F160W IR filter will be used to: 1) derive the skew of the geometric distortion and look for any secular changes over time and/or during the orbital time of target visibility: 2) monitor the optical and mechanical stability of the WFC3/UVIS and IR, using a single filter in each channels; 3) continue of the multi-cycle WFC3 stability and/or or time-dependency; 4) establish if the WFC3 geometric distortion is HST roll-angle dependency.

Description of the observations: The observation of Omega Cen through F606W and F160W as a standard filters in UVIS and IR will be observed with the same pointing but with different roll-angle of the OTA during the three epochs with 3 month apart. Three UVIS exposures in 1 orbit will be observed in the following sequence of off-nominal (~360 degree) roll-angles: 0,+10,+15 degree. Similar to UVIS, three IR exposures in 1 orbit will be observed in the following sequence of off-nominal (~360 degree) roll-angles: 0,+10,+15 degree. In order to improve the schedule, a small range of roll is allowed at each specific roll angle. The order of the exposures in each orbit is specified by a SEQUENTIAL Special Requirement and the order of the orbits is specified by AFTER Special Requirements. To maintain accurate pointing control, 2-guide star acquisitions are used. If suitable guide stars can be found, the same pair of guide stars are used for all 6 exposures. The same sequence will be repeated three times with 3 months apart during the Cycle 21. The observations over three epochs with different HST roll-angle will be used to investigate the dependency of WFC3 geometric distortion over HST roll-angle.

Refining Calibrations with Astrometric Spatial Scanning: Time Dependence

Number of external orbits: 3

Number of internal orbits: 0

Goals: This program is a lighter version of CY20 program 13101 to look for a time-dependence in the ability to align sources to <1 milli-pixel. The program uses the enhanced astrometric precision enabled by spatial scanning to reach <40 micro-arcsecond astrometry (<1 milli-pixel) with WFC3-UVIS. In CY20 we 1) identified finer corrections to the geometric distortion 2) calibrated effect of breathing on the precision of source registration 3) characterized the boundaries and orientations of the WFC3 lithograph cells. We now plan to use three orbits of HST to measure any time dependence in the results collected so far.

Description of the observations: As we did in CY20, we will observe the open cluster M35, which has many (but is not overcrowded with) stars with 11<V<16 mag, the optimal brightness range for high SNR with spatial scanning calibration. The position of M35 allows for observations separated by a few days with a 180 degree orientation change, and a greater leverage on geometric distortion. The field has been selected to contain ~25 stars with 11<V<16 with positions that scan over the lithograph cell boundaries to measure the X-position cell discontinuities.

We would obtain 5 sequential 350 second scans (in the Y direction) per orbit (using a combination of F606W, F621M and F673N), designed to measure the variation in astrometry due to orbital breathing (typically a 3 micron, monotonic change during the orbit). We will then repeat the observations of the same field but with a 180 degree orientation change to calibrate static, residual errors in the present geometric distortion maps. The rotation of the spacecraft can increase the temperature in the telescope. To verify the impact of such a temperature change on our measurements we will rotate the telescope again by 180 degree and observe the field a third time. The total cost is 3 orbits.

Characterization of IR Traps

23 external and 8 internal orbits will be used to:

1.* Improve our current model for persistence – 8 internal + 8 external

2.* Characterize the effect of traps in exosolar planet studies – 15 external orbits

An improved model of persistence

Number of external orbits: 8 Number of internal orbits: 8

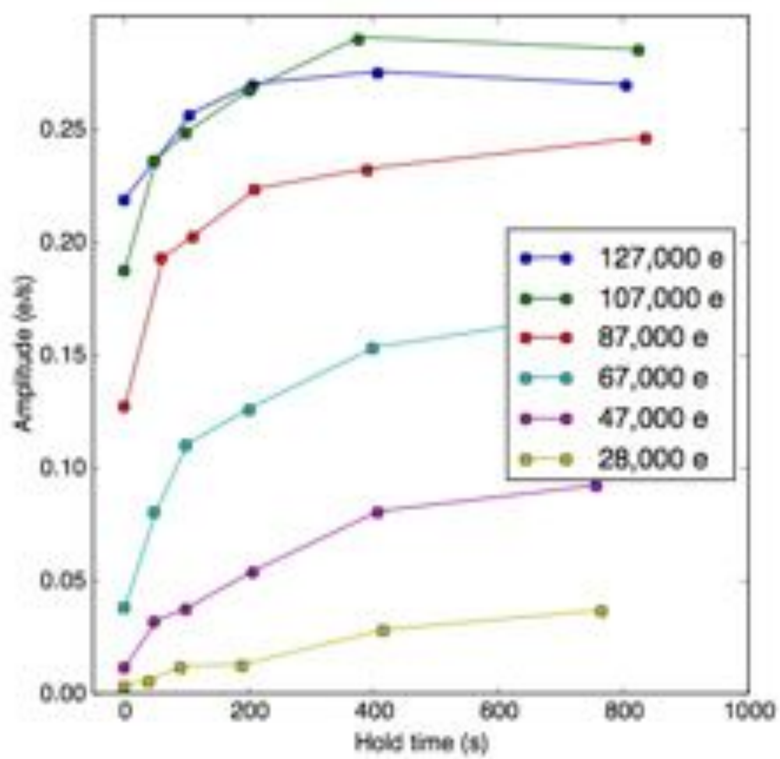
Goals: In cycle 20, we demonstrated the persistence in the WFC3/IR detector depends not only on the fluence obtained in an exposure, but also the time a pixel was held at a high fluence level. However, we do not have data taken with enough different exposure times to develop a quantitative model of persistence that takes into account the length of an exposure. (Specifically at present we only have 2 points, one for an exposure time of 350 s and the other for an exposure time of 702 s.)
The goal of this proposal is to obtain enough data to measure the persistence in the WFC3/IR channel for exposures ranging from 50 to 2000 s. This proposal will enable us the development of an improved model of persistence for incorporation into the software that is used to predict persistence, and is provided to user's as an add-on data product.
Currently although we flag areas of suspected persistence, and can, by inspecting the images and varying parameters in the model, largely subtract persistence, we cannot do this automatically. An improved model of persistence would give us a better understanding of traps in the WFC3 IR detector, and would allow us to provide a better data product for GOs today and archival users in the future.

Description of the observations: Each visit will consist of multi-accum exposure of Omega Cen (or another bright extended target) followed by a series of darks that will extend through an entire orbit to measure persistence for 3000 seconds after the exposure. (A true dark, with a CSM move, will not be required.) Each visit will require 2 orbits

We propose to observe Omega Cen with single multi-accum exposures lasting approximately 50, 100, 200, 500, 800, 1100, 1500, 2000 s in order to determine how our existing model needs to be modified to accurately subtract persistence from the data. Broad filters with be used for the short observations and narrow filters for the long observations to obtain a good sampling of stars at all relevant fluence levels --> 2 orbits x 8 visits --> 16 orbits (8 external orbits; 8 internal orbits)

Cycle 20 test showing effect of hold time on persistence

- This was a test to show at different levels of fluence how persistence varied with time
- This test used the tungsten lamp and a series of darks to measure the persistence
  - Special commanding allowed us to turn off the tungsten lamp in the middle of the exposure
  - Hold time is the time between lamp turn-off and the end of the multi-accum exposure
  - Persistence at 1000 seconds is plotted.
  - The power law slope is also flatter the longer the hold time.
  - The test demonstrates that traps involved in persistence have finite trapping times
- While observations of this type have enabled us to create a qualitative model of persistence incorporating trapping time, they are too far from normal observations to allow us to make the model quantitative



Mitigating Systematic Effects in Exoplanet Observations

Number of external orbits: 15 **Number of internal orbits:** 0

Goals: Observations of exoplanet transits are limited by the effects of traps which reduce the apparent flux from an object at the beginning of orbits. The effect is worst on the first orbit of a visit, but is also present in subsequent visits, due to the fact that observations cease during earth blockage. As a result, the current effective limit on the detection of a exoplanet eclipses is about 0.2% of the light. If the current experiments are successful, this limit could be reduced substantially, enabling the detection of relatively smaller planets (though one still would not be expected to reach the holy grail of an earth-like planet transiting an earth-like star, which would require 0.001%).

We propose to test two possibilities for filling the traps that cause this problem:

• Using the Tungsten lamp before the first visit and during orbit occultations to fill the traps;

• Holding charge on the detector through occultation by preventing a reset on the last exposure to keep traps from emptying.

The goal of this program is to determine whether either of these mitigation approaches is viable; if they are more orbits will be required for optimization.

Description of the observations: Each visit will involve a CVZ observation of a bright Spitzer standard. We use CVZ targets to minimize the amount of special commanding/scheduling that is going to be required for these experiments.

Tungsten lamp tests: Visits will consist of an Tungsten lamp exposure, a scanned grism observation of target star (simulating an exoplanet transit observation), a Tungsten lamp exposure during what would be an occultation for a non-CVZ observation, a second set of grism observations. Each test of this type requires 2 CVZ orbits. (No new special commanding is needed, but we note that this test is CSM movement intensive.) We propose 3 examples of this type, varying the target flux from 30,000; 45,000; 60,000 e (since we know the trap density rises with flux)--> **6 orbits.**

Holding charge tests: Visits will consist of a scanned grism observation, a procedure to keep charge on the detector during the observation, a 2nd grism observation, a 2nd “occultation”, and a 3rd “grism” observation. To keep light on the detector is the very last multiaccum will be long enough to span the entire “occultation” period. New special commanding will be required to control the blank filter. We propose 3 iterations of this, again varying the target flux. ---> **9 orbits.**

We propose to carry the holding charge tests early in Cycle 21 in order that a decision can be made whether to enable this as a mode for Cycle 22.

Trapping Effects in Scanned Exoplanet Transit Observations

- Example of problem being seen in transit observations
- Each visit consisted of 4 orbits
- Observations involved 100 second exposures with the grism while scanning at a rate of 0.1 arcsec/sec
- Total flux in electrons is shown.
- Each datapoint represents one 100 second exposure
- GOs typically take exposures of this type, discard the first orbit and model the effect in subsequent orbits

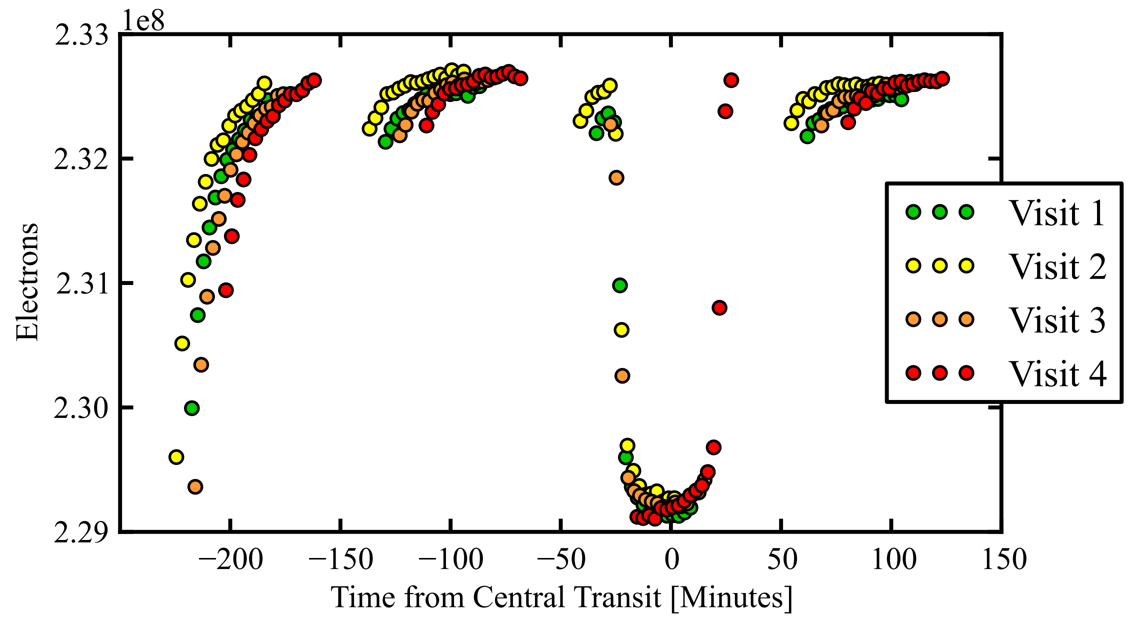


Figure courtesy Jacob Bean et al.

WFC3 Photometric performance

28 external orbits will be used to:

1. Measure the photometric throughput of WFC3 in a series of key filters every 5 weeks to validate instrument throughput stability – 10 orbits.

2.* Check photometric zero-points for all WFC3 UVIS and IR filters– 18 orbits.

WFC3/UVIS Contamination Monitor

Number of external orbits: 10

Number of internal orbits: 0

Goals: Periodically measure the photometric throughput of WFC3 during the cycle in a subset of key filters in the UVIS channel. The data provide a monitor of the flux stability as a function of time and wavelength as well as check for the presence of possible contaminants on the detector windows.

Description of the observations: The target is the same as in past cycles: the white dwarf spectrophotometric standard GRW+70d5824. One orbit is required per iteration. The observing cadence, once every 5 weeks, is chosen to be deliberately out of synchronization with the monthly anneals in order to sample the phase space. Each iteration of the monitor will obtain dithered subarray observations of the standard star in a subsample of filters in the UVIS, including the UV grism. To help reduce CSM cycles, the IR monitoring which previously had been included here will be performed as part of the IR photometric proposal.

NOTE: Cycle 20 trending suggests a possible 0.1% drift per year in UVIS channel.

Orbits required: 10 = 1 orbit every 5 weeks for the duration of the cycle. The last Cycle20 iteration has a plan window start of Nov 4, 2013 so 10 iterations will take the Cycle 21 monitoring through the end of Oct 2014.

WFC3 UVIS and IR Photometry & Contamination Monitor

Number of external orbits: 18

Number of internal orbits: 0

Goals: Monitor the photometric throughput in all WFC3 UVIS and IR filters used during Cycle 21 by GO programs, measure zeropoints and determine color term corrections. The data provide a monitor of the UVIS/IR flux stability as a function of time, wavelength and source brightness. This is a continuation of Program 13089. NOTE: Cycle 20 trending suggests a possible 0.1% drift per year in UVIS channel.
B) Monitor effects of contamination in all WFC3 IR filters. This is a continuation of Cy17-Cy20 contamination monitor programs (moved from UVIS Contamination Monitor to reduce CSM motions).

Description of the observations:
WFC3 UVIS:

- Observations of stars GD153 and P330E are obtained in subarrays at two of the four corners of the UVIS imager to monitor changes in the filter transmission in all filters and to provide a monitor for the zeropoints, and color transformation terms
  - 2 stars, Amps B & C [Amps A & D were monitored in Cycle 20]

WFC3 IR:

- Observations of GD153 and P330E are obtained in subarray mode for all IR filters
  - 2 stars, subarray mode, 1 orbit each, mid cycle.
- Observations of GRW+70 are obtained in subarray mode for all IR filters
  - 1 star, subarray mode, 2 orbits separated by 6 months.

Orbits required: 16 orbits for zeropoints, 2 orbits for contamination monitor.

WFC3 GRISMS

17 external orbits will be used to:

1.* Provide a cross check on the sensitivity functions of the -1st and +1st grism spectral orders – 1 orbit
2.* Monitor the UVIS grism flux in chip2 and calibrate its flux in chip 1 – 2 orbits
3.* Monitor the UVIS grism wavelengths stability in chip2 and calibrate the wavelength in chip 1 – 2 orbits
4.* Improve the flux calibration for both the IR GRISMs – 4 orbits
5.* Improve the wavelength calibration for both the IR GRISMs – 4 orbits
6.* Characterize the two-dimensional structure of the IR background – 2 orbits
7.* Confirm the wavelength zeropoints of the IR grisms – 2 orbits

IR Grisms: Cross checking sensitivity functions of hot and cool stars

Number of external orbits: 1 **Number of internal orbits:** 0

Goals: To provide a cross check on the sensitivity functions of the -1st and +1st grism spectral orders. Scanned observations of a G type star, P330E, in the -1st and +1st grism orders show 5%-10% discrepancy in the sensitivity function derived from this star when compared to that of the sensitivity function determined from the WD standards, GD71 & GD153. We propose to obtain scanned spectra of at hot WD at the same locations on the IR array as for P330E (and Vega) to investigate the source of this discrepancy: scan vs. stare mode, hot star vs. cool star.

Description of the observations:
WFC3 IR:

- Scanned spectra of GD 191B2B at the same locations on the IR array as for P330E (and Vega, obtained with Program 12336) to acquire ~50000 e-/pix, at a rate of ~0.004 arcsec/sec (30 sec/pixel)
- 3 positions per grism.

Orbits required: 1 orbit

WFC3 UVIS grism flux calibration

Number of external orbits: 2

Number of internal orbits: 0

Goals: Verify and refine the UVIS **Flux** calibration. These calibration will improve our ability to process currently archived data as well as support current and future UVIS parallel observations.

Description of the observations: 8 pointings (4 per CHIP) of GD-71 using the G280 grism. Three (3) position on each CHIP will repeat (critical as they show +1 and -1 orders) previously observed position and verify the stability of this mode. The remaining five (5) positions will allow us to refine the 2D dispersion solution of this mode (by adding and by replacing failed observations from previous Cycles)

WFC3 UVIS grism wavelength calibration stability and calibration

Number of external orbits: 2

Number of internal orbits: 0

Goals: Verify and refine the UVIS **wavelength** calibration. These calibration will improve our ability to process currently archived data as well as support current and future UVIS parallel observations.

Description of the observations: 8 pointings (4 per CHIP) of GD-71 using the G280 grism. Three (3) position on each CHIP will repeat (critical as they show +1 and -1 orders) previously observed position and verify the stability of this mode. The remaining five (5) positions will allow us to refine the 2D dispersion solution of this mode (by adding and by replacing failed observations from previous Cycles)

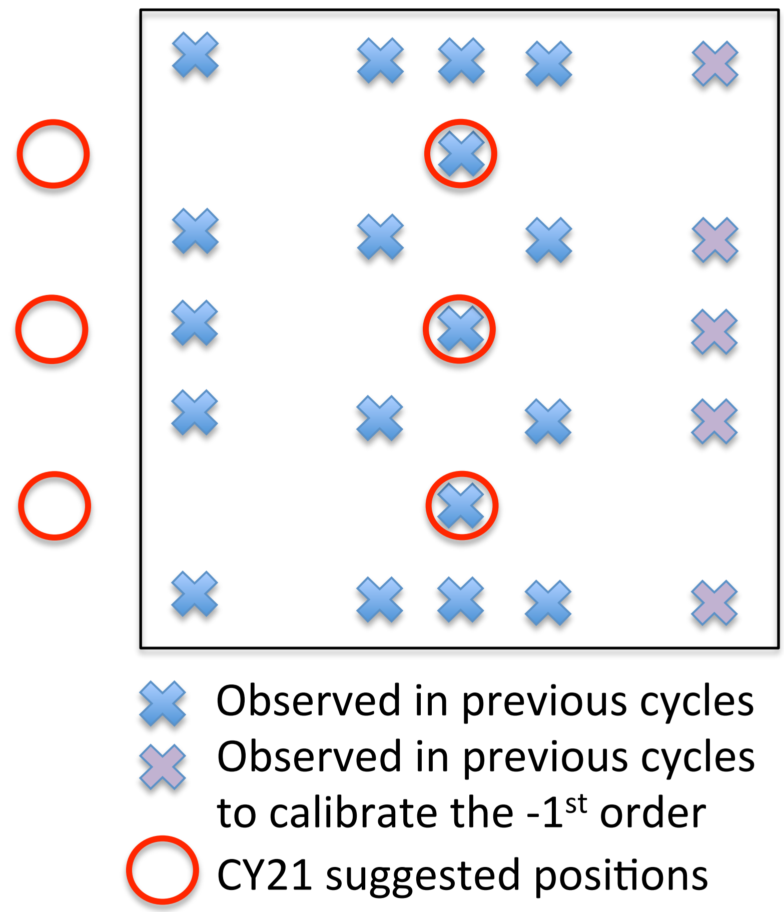
WFC3 IR grisms flux/trace calibration stability and calibration

Number of external orbits: 4

Number of internal orbits: 0

Goals: Verify and refine the **flux** calibration

Description of the observations: 6 pointings of GD71 using the G102 and G141 grisms. 3 previously observed positions and add 3 new positions to outisde and left of the field-of-view to better test and calibrate the 2D variability of the grism wavelength dispersion relations.



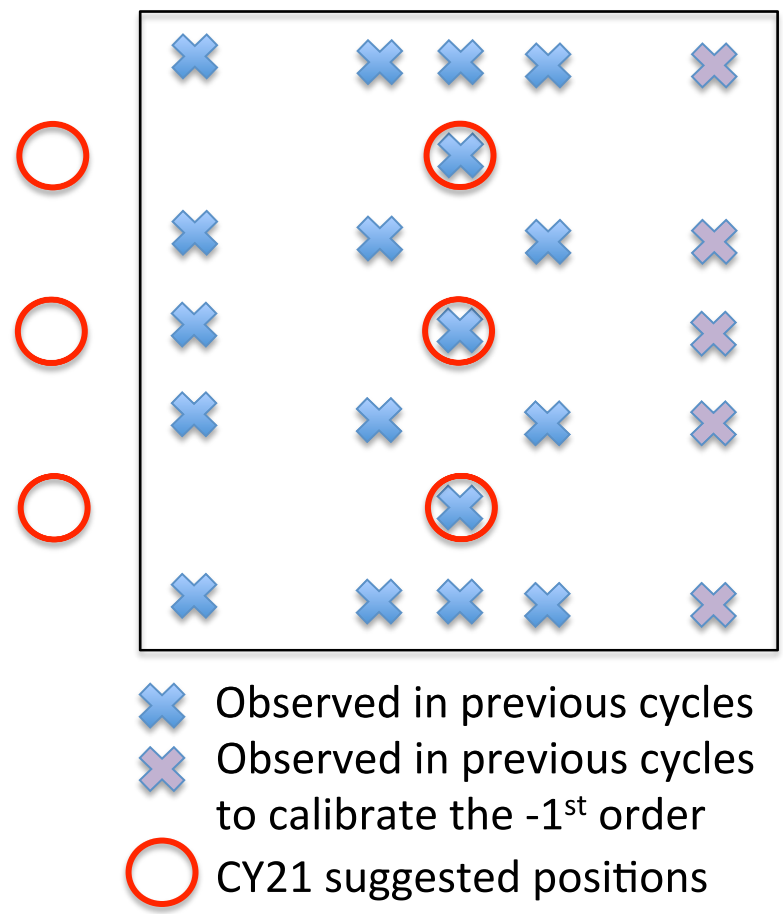
WFC3 IR grisms wavelength calibration stability and calibration

Number of external orbits: 4

Number of internal orbits: 0

Goals: Verify and refine the **wavelength** calibration

Description of the observations: 6 pointings of VY-22 using the G102 and G141 grisms. 3 previously observed positions, and add 3 new positions outside and left of the field-of-view to better test and calibrate the 2D variability of the grism wavelength dispersion relations.



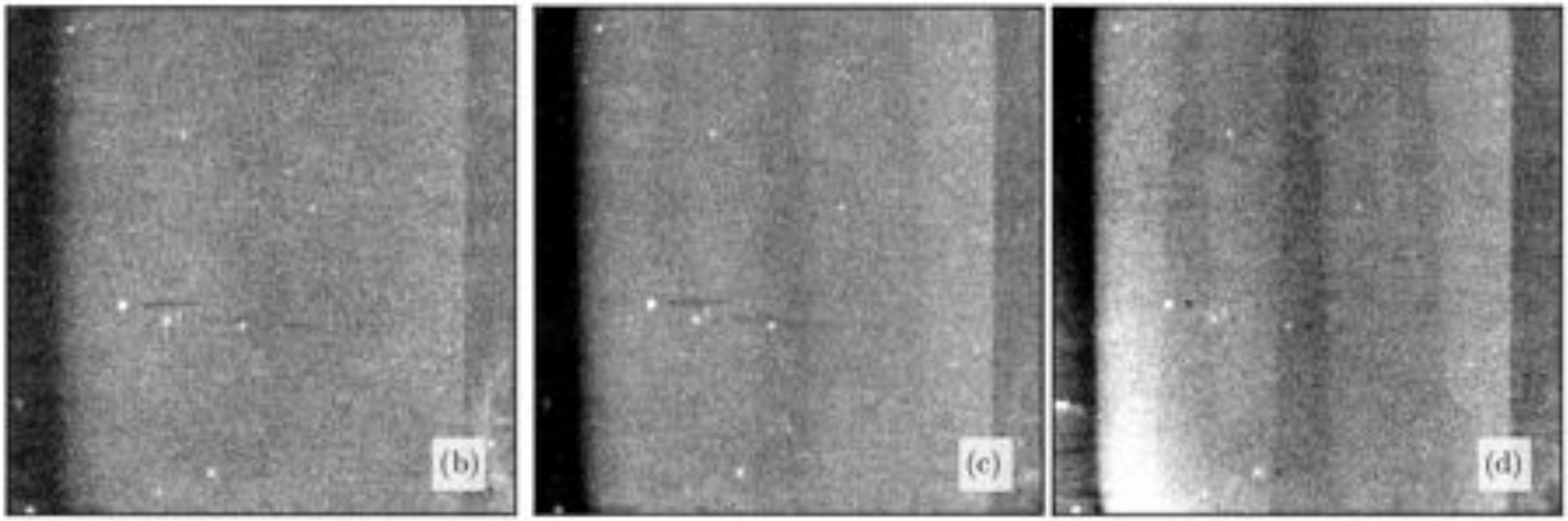
IR Grism Sky Characterization

Number of External Orbits: 2

Number of Internal Orbits: 20

Goals: WFC3/IR grism observations of faint galactic and extragalactic fields are background-limited and the background itself shows complex two-dimensional structure that is difficult to subtract across the whole detector. This background structure varies as a function of intensity, the relative contributions of earthshine and zodiacal light, and perhaps the orientation of the earth limb with respect to the target field. This program will help to eliminate the background structure as a significant source of systematic error for extracting G102 and G141 spectra of faint sources.

Description of the Observations: With 20 internal orbits, divided between G102 and G141, we will use the dark earth as a uniform illumination source to obtain characteristic background images with higher S/N than can be obtained from masking/stacking many individual science frames. With 2 external CVZ orbits (1 each for G102 and G141 in a single visit), we will obtain a time series of background images ranging from well above to nearly grazing the earth limb to characterize how the intensity and structure of the background varies as a function of earth limb angle.



Masked and stacked G141 sky images made from the 3D-HST (12177,12328) and AGHAST (11600) programs (Brammer et al. 2012, ApJSS). The two-dimensional structure is a result of the zodiacal+scattered earthglow background intensity and spectrum dispersed by overlapping spectral orders. Though the **left two panels** are similar, the contrast of the dark band at the left of the images is quite different. The **right panel** is taken from exposures with unusually high background levels that were taken close to the earth limb in the CVZ (the GOODS-North field).

This also illustrates that the blobs can enable measuring the earthglow spectrum as decrements in the approximately uniform background.

Recalibration of the IR Grism Wavelength zeropoints with IC5117

Number of External Orbits: 2 **Number of Internal Orbits:** 0

Goals: To confirm the wavelength zeropoints of the WFC3/IR grisms with IC 5117. In Cycle 20, we discovered that the pedigree of Vy 2-2's line lists, the PN used for wavelength calibration, was incomplete. At wavelengths shortward of 1.2 microns the provenance of the spectrum is unknown, and does not match the observed Vy 2-2 spectrum. At wavelengths longer than 1.2 microns, we use the Hora et al (1999, ApJS, 124,195) published spectrum of Vy 2-2. The PN IC 5117 is bright, compact, and has a published, high resolution, 0.8 to 2.5 micron spectrum (Rudy et al 2001, AJ, 121, 362). Its spectral lines have been confirmed against the NIST spectral line catalogs. We thus propose to recalibrate the grism wavelength zeropoints with a properly pedigreed planetary nebula, and, improve the accuracy of the solution to between 0.05 and 0.1 pixels.

Description of the Observations: We will observe IC 5117 in 3 positions on the detector, with both G102 and G141 grisms, and, in the +1st and -1st orders.

Flatfield Calibrations

We request 14 external and 555 internal orbits to:

1.* Improve inflight UVIS flatfields for the filters F218W and F280N via spatial scan – 8 external orbits
2.* Evaluate the accuracy of the UVIS flatfields for the filters F218W and F280N by stepping a spectrophotometric calibration standard across the detector – 4 external orbits
3.* Monitor a population of UVIS pixels with anomalous QE - 24 internal orbits
4. Monitor the health of the UVIS filters via int-flats -13 internal orbits
5. Monitor the health of the IR filters via int-flats-18 internal orbits
6.* Monitor the health of the CMS mechanism by observing the bright earth – 400 internal orbits

WFC3 UV Inflight Flats with Spatial Scans

Number of external orbits: 8

Number of internal orbits: 0

Goals: Obtain a low-frequency flat field in each of two UV filters: F218W and F280N.

Description of the observations: We will observe a UV bright double star with boustrophedonic spatial scans. Because UV-bright stars are few and far between, even in clusters, the traditional method of obtaining an L-flat, namely taking many large-dithered staring-mode exposures is ineffective in the UV. Using the scanning technique and one double star, we can determine the inflight flats in the UV filters F218W and F280N. For each filter, we require two HST orbits for each visit that scans multiple times in X and in Y, and we require two visits with a relative orient difference of 90 degrees. Hence 8 orbits total.

WFC3 UVIS Spatial Sensitivity

Number of external orbits: 4 **Number of internal orbits:** 0

<u>Goals:</u> Step a photometric standard across the detector to measure sensitivity residuals in the 2 remaining UV flat fields which were obtained in ambient conditions during ground testing. These include F218W & F280N, which make up 1% and 3% of the total useage for the UVIS detector in Cycle 21.

This will supplement existing observations in prior UVIS stepping programs 12090 (F336W), 12707 (F275W, F438W, F606W, F814W), and 13096 (F225W, F606W, with post-flash).

<u>Description of the observations:</u>

Stepped photometry in F225W & F275W obtained in prior cycles shows residual spatial variations of ±2-3%. Because the UV ground flats were obtained warm, these residuals form a 'crosshatch' pattern due to detection-layer structure in the CCDs which is not corrected by the inflight low-frequency flat field corrections. We propose 2 orbits to step a standard star across the detector in F218W and F280N to help constrain the amplitude of the 'crosshatch' pattern as a function of wavelength. The observations will include post-flash to mitigate the effect of CTE losses.

UVIS Pixel-to-Pixel QE Variations via Internal Flats Monitor

Number of External Orbits: 0 **Number of Internal Orbits:** 24

Goals: This program continues to monitor the population of pixels exhibiting anomalous QE variations between anneals. These pixels are randomly distributed across the detector and develop lowered sensitivity during the time between anneals. The sensitivity loss is greater in the blue than in the red and the population that develops is seemingly unique per each cycle. This program will continue to monitor the pixel-to-pixel QE variations across the detectors as was done in the previous cycles.

Description of the Observations: Using the F438W and F814W filters and the Tungsten lamp, we will take 4 internal orbits per month for 6 months. These orbits will bracket the monthly anneal and obtain flats between anneals to monitor population development. The tungsten lamp will be warmed up using a 60 second subarray exposure which will be taken at the beginning of each orbit. This warm-up is essential as it guarantees each flat will be as similar as possible to those taken in previous cycles, thus allowing a time monitoring of this time-evolving pixel population.

All orbits will require non-interrupt to minimize cycling of the limited-lifetime tungsten lamp. Exposure times will be the same as the previous cycle, achieving a mean value of ~37,000 counts per pixel.

These observations will allow us to monitor the population of anomalous pixels as they develop throughout the cycle and compare these data with the previous cycles.

WFC3/UVIS Internal Flats

Number of external orbits: 0

Number of internal orbits: 13

Goals: Monitor the stability of the UVIS pixel-to-pixel sensitivity in all filters by obtaining internal flat fields with the tungsten and deuterium lamps.

Description of the observations: We will acquire internal flats in all UVIS filters once early in Cycle. This consists of 3 orbits with the D_2 lamp for the filters F218W, F200LP, F225W, F275W, F280N, F300X, F336W, F343N, F373N, F390M, F390W, F395N, FQ232N, FQ243N, FQ378N, and FQ387N, and 8 orbits with the Tungsten lamp to acquire the remaining 46 filters. Observations in the 4 filters F390W, F438W, F606W, and F814W with the tungsten lamp will be repeated 2 times over the cycle for a total of 2 orbits.

This is a continuation of UVIS internal flat programs 11432, 11914, 12337, 12711, 13097.

WFC3 IR internal flats

Number of external orbits: 0

Number of internal orbits: 18

Goals: Monitor the stability of the IR pixel-to-pixel sensitivity in all filters by obtaining internal flat fields with the tungsten lamp.

Description of the observations: We will acquire 2 exposures for the full set of IR filters once in the middle of the cycle. This requires 12 orbits (6x2). In addition we will acquire 3 exposures in each of the broad band filters F105W, F110W, F125W, F140W, and F160W to monitor those flats 2 times during the cycle (early and at the end). This requires other 6 orbits (2x3 orbits) for a total of 18 internal orbits.

This is a continuation of IR internal flat programs 11433, 11915, 12338, 12712, 13098.

Blobs with IR Earth Flats

Number of External Orbits: 0 **Number of Internal Orbits:** 400

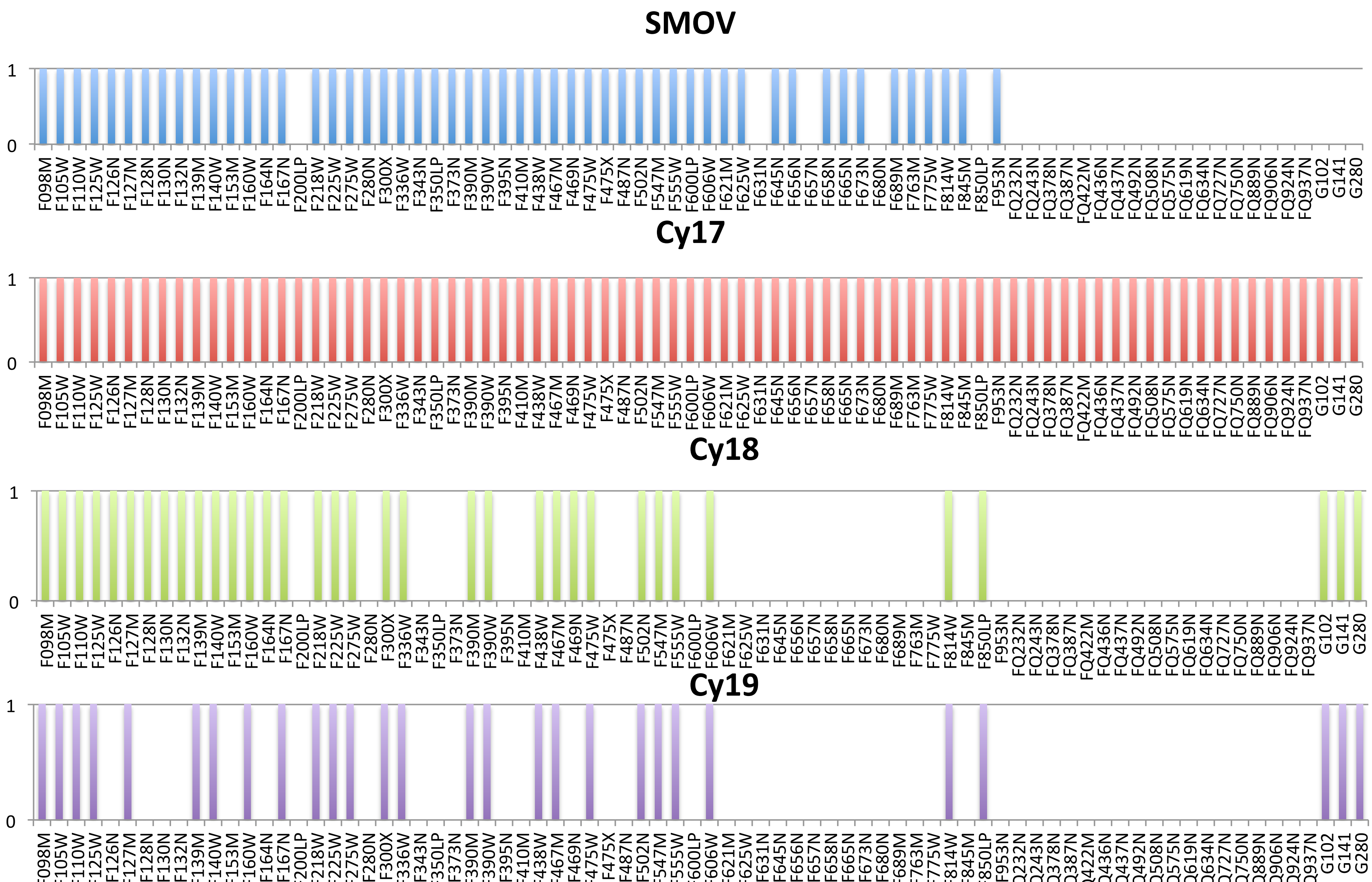
Goals: Monitor the position of the Channel Select Mechanism (CSM) as often as practical and sufficiently often that we might detect operational anomalies in a timely manner, should they occur. Also monitor the accumulation of new IR blobs.

Description of the Observations: Identical to the current CSM monitoring program 13499 and the completed program 13068. Each visit is a single short exposure (103 s) that typically gives adequate S/N ratio in F153M to measure well the IR blob positions and hence the CSM position while also not risking saturation and associated after-images in the IR detector (i.e. it is designed to avoid being a "bad actor").

This program is scheduled as opportunities occur: each visit is required to not demand a new move of the CSM to the IR-channel position nor redundantly observe a given position more than once. At the current monitoring rate of ~1 observation per day, we expect ~400 visits are adequate for the coming HST cycle. For convenience we suggest four program numbers, each of which will have 100 visits.

SUPPORTING MATERIAL

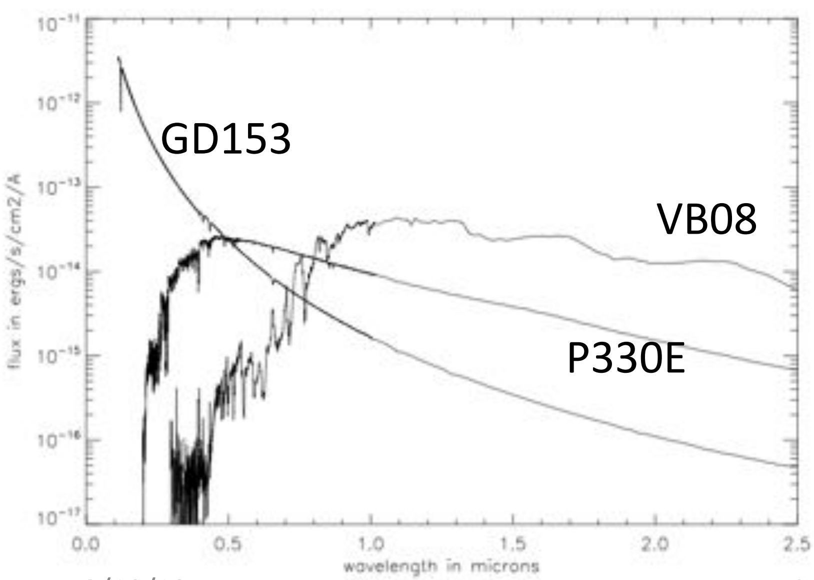
UVIS filter calibration



UVIS spectro-photometric standards

Amp	A (62 +14)	B (62 + 14)	C (62 +14)	D (62 + 14)
GD153	4	4	4	4
P330E	4	4	4	4

Number of orbits for 62 UVIS filters, 14 IR filters
Orbit includes overheads
2 point dither, SNR=200, minimum exptime = 1 sec



Vega mags	B	V	R	I	J	H
GD153	13.17	13.40	13.8	13.3	14.012	14.2
P330E	12.972	12.9	12.56	12.212	11.76	11.45
VB08	18.7	16.7	16.61	12.24	9.776	9.2