Instrument Science Report WFC3 2012-04

WFC3 Cycle 19 Calibration Program

E. Sabbi & the WFC3 Team

March 16, 2012

Abstract

The Cycle 19 WFC3 Calibration Program runs from October 2011 through September 2012 and is designed to measure and monitor the behavior of both the UVIS and IR channels. The program was prepared with the actual usage of WFC3 in mind, to provide the best calibration data and reference files for the approved scientific programs. During Cycle 19 the WFC3 team is using 125 external and 1587 internal orbits of HST time divided in 29 different programs, grouped in six categories: Monitor, Photometry, Spectroscopy, Detectors, Flat-fields, and Image Quality

Introduction

The Wide Field Camera 3 (WFC3) is a panchromatic (wavelength coverage ranging from 200 nm to 1700 nm) 4^{th} generation instrument of the *Hubble* Space Telescope (HST). WFC3 has replaced the Wide Field Planetary Camera 2 (WFPC2) during the last HST servicing mission (SM4) in May 2008.

WFC3 has two independent channels: the UVIS channel, sensitive to the wavelength between 200 nm and 1μ, and the IR channel, operating between 800 nm and 1.7μ. The UVIS

Copyright © 2012 The Association of Universities for Research in Astronomy, Inc. All Rights Reserved.

channel uses two 4096×2051 pixel CCD detectors with a pixel scale of $0''.0395$ and a field of view (FoV) of $162'' \times 162''$. It is equipped with one UV grism and 62 narrow-, medium, and broad-band filters, 42 of which cover the entire UVIS FoV, and the remaining 20 filters being organized in 5 sets of "quad" filters.

The IR channel consists of a 1024×1024 HgCdTe detector array, of which the central 1014×1014 pixels are used for imaging. It has a FoV of $136'' \times 136''$ and spatial resolution of $0''.135 \times 0''.121$. This channel has 15 broad, medium and narrow band full-frame filters, and two IR grisms. The WFC3 Instrument Handbook (Dressel, L. 2011) provides a complete description of WFC3, while information on how to reduce the WFC3 data can be found in the Data Handbook (Rajan et al. 2010).

CY19 WFC3 Usage

In CY19 WFC3 is the most widely requested instrument, in prime and parallels mode, using 48.6% of the HST orbits available for science. Table 1 shows the distribution of the approved GO proposals between the WFC3 channels and observing modes.

WFC3 Program Type	IR Imaging	IR Spectroscopy	UVIS Imaging	UVIS Spectroscopy
Prime %	14.5	3.6	19.0	1.2
Coordinate Parallel %	2.7	0.0	47.8	0.0
Pure Parallel %	42.2	25.0	31.3	0.0

Table 1: *Percentage of HST time used by the WFC3 observing modes*

As in the two previous cycles, both the WFC3 channels are equally popular:

- During CY17, 92% of the WFC3 exposures were acquired in imaging mode, 49% with UVIS and 51% with the IR channel;
- In CY18, the IR channel was the most popular, taking 78% of the WFC3 exposures. CY18 was characterized by a very high request for spectroscopic observations;
- In CY19, 44% of the exposure are acquired with UVIS and 56% with the IR channel; in this cycle 77% of the WFC3 exposures are acquired in imaging mode.

A closer look to the GO and multi-cycle treasury (MCT) proposals shows that in CY19 the WFC3/UVIS channel acquires 50% of its exposures with a UV filter, 25% of its exposures are acquired either in the F606W or the F814W filters, and 13 of the UVIS filters acquire each more than 100 exposures. We have a request for 12 of the 15 WFC3/IR filters, with 8 acquiring each more than 200 exposures. The WFC3/IR grism G141 alone will acquire nearly 1500 exposures. The usage of the WFC3 filters in CY19 is summarized in Figure 1. Figure 2 shows the usage of the WFC3 filters over the three cycles (17, 18 and 19).

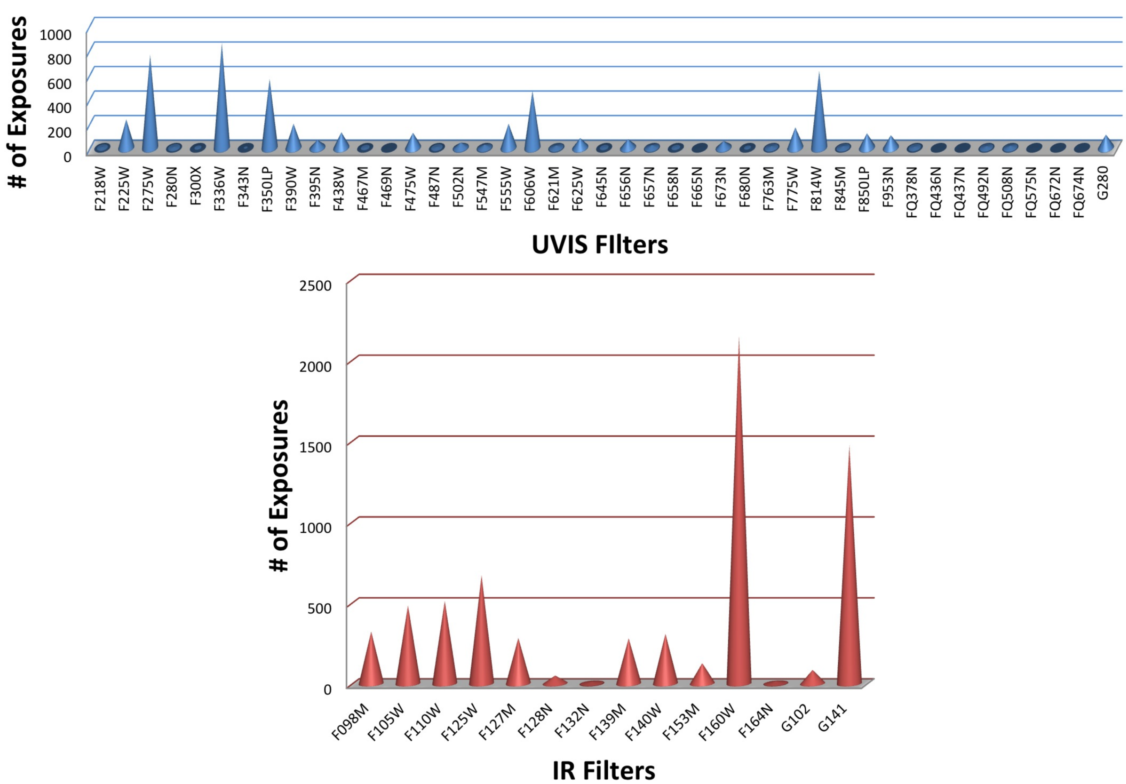

Fig. 1.— WFC3 filter usage (GO+MCT) in CY19. Data for the UVIS channel are shown in blue, for the IR in red.

Calibration Requirements

The WFC3 calibration plan for CY19 was built to support the variety of observational modes requested by the GOs, and to monitor the performances of two WFC3 channels. The 29 calibration activities (see Table 2) are grouped into six categories: Monitor, Photometry, Spectroscopy, Detectors, Flat-fields, and Image Quality.

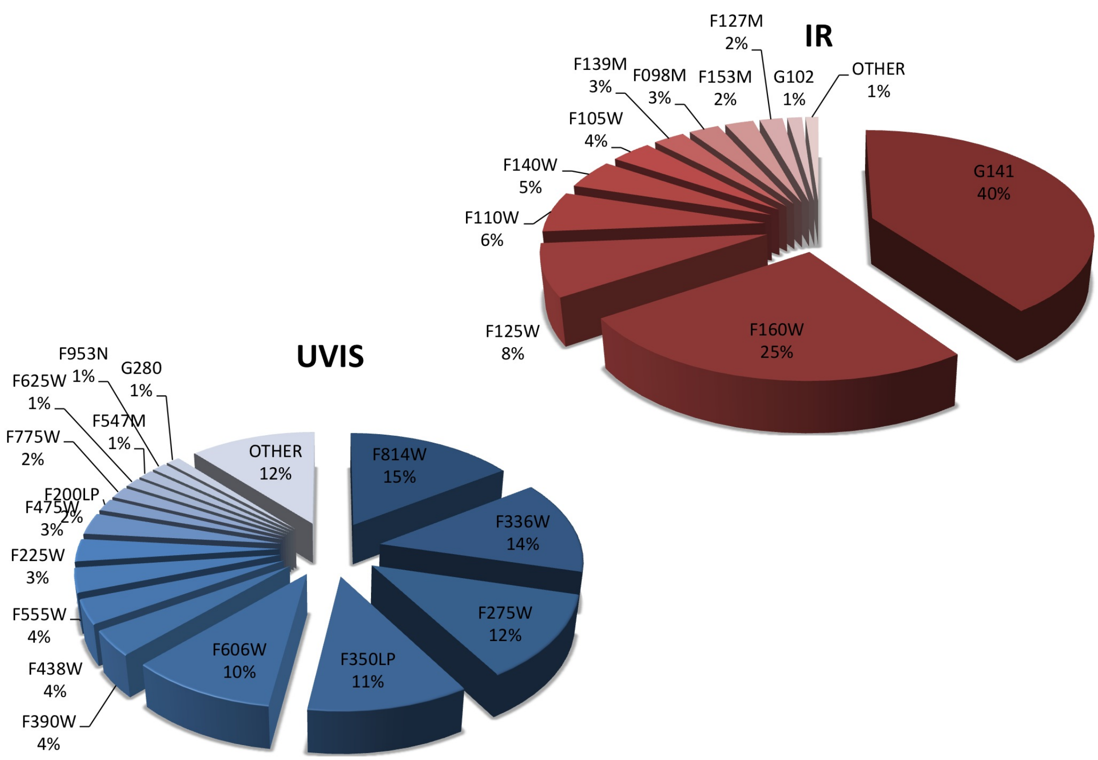

Fig. 2.— WFC3 cumulative filter usage in the cycles 17 + 18 + 19. UVIS is in blue and IR is in red.

Monitor Activities

As in the previous two Cycles (Deustua et al. 2009, Deustua 2010), one of the main goals during CY19 is to monitor the main properties of the instrument. The health of the two UVIS CCDs is checked using 951 internal orbits, divided as follow:

1. 78 (whose cadence has beed synchronized with the other HST instruments) to perform a monthly anneal;
2. 130 to monitor the hysteresis (a.k.a. bowtie, Baggett & Borders 2009) effect via a series of unsaturated and saturated internal flats;
3. 730 to perform a daily monitor of the CCDs behavior using a series of dark and biases;
4. 13 verify the stability of the gain in the 4 UVIS quadrants for all the available binning

ID	Program Title	No. of Exposures		PI
		Ext.	Int.	
12687	UVIS Anneal		91	S. Baggett
12688	UVIS Bowtie Monitor		130	T. Borders
12689	UVIS CCD Daily Monitor		730	S. Borders
12690	UVIS CCD Gain Stability		13	C. Pavlovsky
12691	UVIS CTI Monitor (EPER)		24	V. Kozhurina-Platais
12692	UVIS CTE Monitor (Star Clusters)	14		K. Noeske
12693	UVIS Charge Injection	6	50	K. Noeske
12694	IR Persistence Strength	9	67	K. Long
12695	IR Dark Monitor		235	M. Dulude
12696	IR Linearity Monitor	6	18	B. Hilbert
12697	IR Gain Monitor		16	B. Hilbert
12698	WFC3 Contamination & Stability Monitor	17		S. Baggett
12699	WFC3 Photometric Calibration & Calibration Flux Ladder	16		S. Deustua
12700	Extending the Range & Precision of the Count Rate non-Linearity	4		A. Riess
12701	WFC3 PSF Wings	6		L. Dressel
12702	IR Grisms: Flux/Trace Calibration & Stability	8		J. Lee
12703	IR Grisms: Wavelength Calibration & Stability	8		N. Pirzkal
12704	UVIS Grism: Flux & Calibration	3		N. Pirzkal
12705	UVIS Grism: Wavelength Calibration & Stability	3		N. Pirzkal
12706	UVIS Flare Wavelegth Dependence	2		J. Mack
12707	UVIS Spatial Sensitivity	10		A. Rajian
12708	IR Spatial Sensitivity	4		A. Rajian
12709	UVIS & IR Moonlit Flats		50	C. Pavlovsky
12710	UVIS Bright Earth Flats		20	J. Mack
12711	UVIS Internal Flats		20	A. Rajan
12712	IR Internal Flats		33	T. Dahlen
12713	Spatial Scanned L-flat Validation Pathfinder	7		P. McCollough
12714	UVIS & IR Geometric Distortion	2		V. Kozuhrina-Platais
12784	Characterization of UVIS Traps Via Charge-Injected Biases		90	E. Sabbi
	Total Allocated Orbits	125	1587	

Table 2: *CY19 Calibration Proposals.*

modes by taking a series of internal flats over a range of integration time.

336 internal orbits are used to monitor the performances of the infrared array. The orbits are organized as follow:

1. 235 to obtain IR dark calibration files. The number of orbits is dictated by the observing modes requested by GOs. Because of the dark stability these calibrations can be accomplished with 45% fewer orbits than in CY18.

2. 18 (saturated internal flats) to monitor the IR non-linearity and update the calibration reference file, 6 external orbits (low and high signal ramps of 47 Tuc) are also used.

3. 16 to verify the stability of the IR channel gain via a series of lamp flats. Different orbits are required to avoid persistence effects.

4. 67 (full darks) are used to provide a model that can remove persistence to 1/2 of the dark current rate. Of the 67 darks, 40 will be scheduled after selected GO programs to quantify the persistence. Nine external orbits are also used to image ωCentauri at different positions to monitor persistence effects from point sources.

In CY19 special attention is dedicated to monitoring, characterizing and correcting the charge transfer inefficiency (CTI) in the UVIS data. Twenty external and 164 internal orbits are used, divided as follows:

1. 2 internal orbits per month measure the CTI via Extended Pixel Edge Response (EPER, Kozhurina-Platais et al. 2009; Kozhurina-Platais et al. 2011);

2. 14 external orbits are used to observe stellar fields characterized by different levels of crowding and background (2 fields in 47 Tuc and 1 in NGC 6791) to calibrate the photometric and astrometric CTI corrections;

3. 6 external orbits are used to observe 47 Tuc with line 17 Charge Injection (CI). 50 internal orbits are necessary to obtain the CI biases;

4. 90 internal orbits are used to monitor the growth of the traps number in the UVIS CCDs with time.

Spectroscopy Activities

33% of the WFC3 exposures in CY19 are acquired with one its three grisms. For this reason a total of 22 external orbits are used during this cycle to derive:

1. a flux calibration of the IR grisms G102 and G141 over the whole detector (8 orbits);

2. a flux calibration of the UVIS grism G280 over the whole FoV (3 orbits);

3. refine the wavelength calibration of both the two IR grisms (8 orbits);

4. refine the wavelength calibration of the UVIS grism (3 orbits).

Flat-fielding Activities

18 external and 65 internal orbits are used to monitor and validate inflight flat-fields of the UVIS channel. The internal orbits are used to to monitor the high spatial frequency (pixel-to-pixel) variations via tungsten lamp flats (20 orbits), observe the bright Earth and validate the low-frequency flat-filed correction (L-flat) for the UV filters (20 orbits), observe the dark side of the Earth and validate the L-flat correction at the visible wavelengths (25 orbits).

The external orbits are divided as follow: two are used to characterize the wavelength dependence of the optical flare (McCullough 2011, and reference therein) by measuring the strength of the figure 8 ghosts through different filters; 10 to verify the inflight correction of the flats by stepping the spectrophotometric standard G191-B2B across the detector; and the remaining 6 orbits to validate the flare removal and flat inflight correction by perform spatial scanning of HD80606 in 7 different filters.

Similar calibration activities are executed for the IR channel: 33 internal orbits monitor the high spatial frequency variations via internal tungsten lamp flats and other 25 internal internal are used to observe the dark side of the Earth and validate the L-flat correction at near-IR wavelengths. The on-orbit flat-field correction is further checked via spatial scan-imaging of the bright double star HD80606 in 2 different filters (2 external orbits) and by observing the spectrophotometric standard WD 1057+719 in 32 different positions across the detector in three different filters (4 external orbits).

Photometric Performances & Image Quality

17 external orbits of HST time are used to periodically measure the photometric throughput of WFC3 in a series of key filters. Other 16 orbits are dedicated to establish the WFC3 calibration flux ladder from V$\sim$ 5 mag to V$\lesssim$14 mag.

5 orbits are used to check for image stability by measuring the encircle energy of the PSF as a function of radius at 5 different locations on each detector orbits; and two orbits to monitor the secular changes of both the UVIS and IR plate scales.

Four orbits are dedicated to obtain an independent calibration of the IR zero points and a measure of the count rate non linearity between $H = 14$ and 17.

Data, Analysis and Results

As for the previous cycles all analysis and results from CY19 Calibration Programs will be described in Instrument Science Reports (ISRs) and will be available on the WFC3 web site http://www.stsci.edu/hst/wfc3/documents/ISRs/. Updated reference files will be provided to the scientific community when appropriate.

CY19 WFC3 Calibration Proposals

A detailed description of all the CY19 WFC3 Calibration Proposals is given below, in order of assigned proposal ID. As for any other HST observation, the PhaseII of each WFC3 Calibration Proposal is public and can be consulted at the web page http://www.stsci.edu/hst/scheduling/program_information to obtain details on the observing strategy. Table 2 summarizes proposal IDs, titles, number of approved external and internal orbits and PIs.

CAL-12687 WFC3/UVIS Anneal

Number of external orbits: 0 **Number of internal orbits:** 91

Goals: Perform regular anneals to repair hot pixels and acquire internal images to assess the procedures effectiveness. Internal exposures are also used to generate update reference files for the calibration pipeline.

Descriptions of the observations: Anneals are performed once a month, a cadence which optimally interleaves the WFC3 procedure with those for other instruments (one instrument per week). Internal biases, regular and charge-injected, as well as darks are taken before and after each anneal, to provide a check of bias level, read noise, global dark current, and hot pixel population. The bowtie visit provides a "fixing" image and verifies that any hysteresis has been successfully quenched after the anneal. 13 iterations will place the last Cy19 anneal in mid-Sep 2012 (the last Cy18 anneal being scheduled in mid-Sep 2011). This is a continuation of programs 11909 and 12343. Orbits required: $91 = 13 iteration * 6$ orbits (2 orbits of bias/dark before, and 2 orbits after, each anneal + 1 anneal + 1 bowtie visit and 1 IR dark after every anneal).

CAL-12688 WFC3/UVIS Bowtie Monitor

Number of external orbits: 0 **Number of internal orbits:** 130

Goals: Monitor hysteresis effect (QE offset).

Descriptions of the observations:

- Three 3x3 binned internal calsystem flat-field (F475X)
- First flat unsaturated (initial bowtie check)
- Second flat heavily saturated (neutralizer)
- Third flat unsaturated (final check)
- Repeat every 3^{rd} day as in Cycle 18

This is a continuation of programs 11908 and 12344

CAL-12689 WFC3/UVIS CCD Daily Monitor
Number of external orbits: 0 **Number of internal orbits:** 730

Goals: Monitor the behavior of the UVIS CCDs with a daily set of bias and dark frames.

Descriptions of the observations: We will perform two visits per day.

Even days (5 images/day) – 1^{st} visit (= 1 orbit): 2 biases, 1×900 sec dark;
– 2^{nd} visit (= 1 orbit): 2×900 sec darks.

Odd days (4 images/day) – 1^{st} visit (= 1 orbit): 2×900 sec darks;
– 2^{nd} visit (= 1 orbit): 2×900 sec darks.

This is a continuation of programs 11905 and 12343.

CAL-12690 WFC3/UVIS Gain Stability
Number of external orbits: 0 **Number of internal orbits:** 13

Goals: The absolute gain of the WFC3 UVIS detector will be measured for each quadrant and compared with previous cycles to check for stability.

Description of the observations: The absolute gain of each quadrant for the nominal detector readout configuration (ABCD, gain = $1.5e^{-}/DN$, bin = NONE) will be measured by taking 8 full frame pairs of internal flat-fields, illuminated with the UVIS default tungsten lamp (TUNG3) through F645N, over a range of integration times to achieve exposure levels from ~ 500 to $\sim 50,000\,e^{-}$. Full frames match the observing mode of the majority of GO programs, provide good statistics, and allow checking for gain variability across the entire detector. This is a continuation of programs 11906 and 12346. Previous measurements have been stable. Because BIN = 2 and BIN = 3 have not been tested since Cycle 17, and there are over 200 instances of these modes in this cycle, we will measure the gain under these modes as well.

Data for the full frame, bin = NONE mode will be collected in 2 epochs, 6 months apart. Each epoch requires 5 internal orbits for a total of 10 internal orbits. For BIN = 2 and BIN = 3 modes there will be 3 orbits visit.

CAL-12691 WFC3/UVIS Internal CTI Monitor (EPER) measurements
Number of external orbits: 0 **Number of internal orbits:** 24

Goals: Measure the UVIS detector CTI via Extended Pixel Edge Response (EPER) method using tungsten lamp flat-field exposures, and establish the CTE loss over time.

Description of the observations: We will acquire short internal flat-fields with the tungsten lamp through the filters F390M, F390W, and F438W with different illumination levels of 200, 400, 800, 1600 and 5000 e^{-}. These observations will be used to monitor UVIS CTE, by measuring the profiles into trailing over-scan region. We will use 2 orbits every month, for a grand total of 24 orbits. This is a continuation of program 12347.

CAL-12692 WFC3/UVIS External CTE Monitor with Star Clusters
Number of external orbits: 14 **Number of internal orbits:** 0

Goals: Monitor charge transfer efficiency (CTE) degradation as a function of epoch and source/observational parameters; calibrate photometric and astrometric corrections, provide data for the Bedin & Andersons model adaptation to WFC3/UVIS.

Description of the observations: Repeat CY18 external CTE monitor (program 12379), continuing the observations with consistent data. Streamlined observations, removed 2000 pxl X-dither, kept 2000 pxl Y-diher. Observe two fields of 47 Tuc and one field of NGC 6791 to cover different crowding effects. Use filters F606W and F502N to cover different backgrounds. 1 orbit per target, 3 epochs = 9 orbits. In addition 1 orbit in CVZ to collect multiple background level sampling observation.

CAL-12693 WFC3/UVIS Charge Injection

Number of external orbits: 6 **Number of internal orbits:** 50

Goals: Improve the characterization of the Cy19 charge-injection (CI) model (line 17), expand the parameter space for CI usage, and monitoring CTE degradation under CI.

Description of the observations: The first part of the program consists of one iteration of the standard CTE monitor but using CI. This visit should be done close in time to the CTE monitor to allow direct comparison to non-CI results. It will allow an evaluation of CI performance and in conjunction with the charge-injected visit obtained in Spring 2011, an assessment of the temporal behavior of the CI. To do this we will use one external orbit to acquire F606W/F502N Y-dithered long exposures of 47 Tuc using line 17 CI, 20 additional internal orbits will be necessary to acquire CI biases. Other 30 internal orbits will be used to acquire CI bias every ~ 4 months (spread over an interval of 2–4 weeks) to monitor CTE with time. The second part of the program aims to expand STScI experience with CI, while minimizing the required number of external orbits by duplicating selected GO programs (with PI approvals) with CI. We request GO duplications up to 5 orbits.

CAL-12694 WFC3/IR Persistance Strength
Number of external orbits: 9 **Number of internal orbits:** 67

Goals: Provide a model that can remove persistence due to previous visits to less than 0.01 e^{-}/s ($\sim 1/2$ the dark current rate). Quantify how the time pixels are maintained near/above full well affects persistence. Verify that persistence is not changing with time.

Description of the observations: To quantify how the time pixels are maintained near/above full frame affect persistence we will observe ωCen 9 times, with each visit consisting of one or more undithered exposures followed by a series of darks. The 9 visits will be made at 3 different positions in ωCen producing about 1000 saturated stars.

A combination of narrow, medium and broad band filters and multiple exposure will create a range of exposure histories all with about the same saturation level for stars of the same brightness. We will measure persistence as a function of exposure level and histotry.

To measure how accurately the persistence model subtracts in real situation we will attach 2-orbit darks to"Bad Actors" in selected calibration and GO programs. Bad actors are visits after which we normally restrict use for WFC/IR for 2 orbits. We request 40 FULL-orbit internal orbits through out the year.

As an alternative we can use a combination of external and internal orbits to create visits with typical dithered observing sequence, followed by FULL-orbit internal darks, of one or more globular clusters.

CAL-12695 WFC3/IR Dark Monitor
Number of external orbits: 0 **Number of internal orbits:** 235

Goals: Obtain IR dark calibration files necessary to support CY19 observations.

Description of the observations: In order to produce the best quality and most current composite dark calibration files for CY19 external observations, full-frame and sub-array IR dark calibration observations must be taken on a regular basis. These observations will also be used to monitor the stability of hot pixels. Three of the internal orbits will be used to study the behavior and decay of the banding anomaly in full frame darks.

This is a continuation of programs 11929 and 12349. Based on studies of the long-term trending and stability of the dark current, the above calibration goal can be accomplished with 65% orbit less than in CY18.

CAL-12696 WFC3/IR Linearity Monitor
Number of external orbits: 6 **Number of internal orbits:** 18

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 internal flat exposure up to saturation in order to provide a pixel-to-pixel map of the non-linearity of the detector. To manage persistence, each internal flat is preceded and followed by a dark exposure. 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 $S/N \sim 30$. In the high-signal ramps, $V = 20$ stars will be saturated, and $V = 22$ stars will have $S/N \sim 130$. 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 2004). This program is a continuation of program 12352.

CAL-12697 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, taken within a single week about halfway through the cycle, will be used to acquire 16 internal flats for the use in computing the detector gain via the mean-variance technique. To manage persistence effects, the gain internal flats are not taken back-to-back, but in their own orbits. Furthermore, each gain internal flat 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 internal flats are acquired at $\sim 1/2$ full-well to minimize non-linearity corrections. This is a continuation of programs 11930 and 12350. This data will be used to monitor also the declining of the detector.

CAL-12698 WFC3 Contamination & Stability Monitor
Number of external orbits: 17 **Number of internal orbits:** 0

Goals: Periodically measure the photometric throughput of WFC3 during Cy19 in a subset of key filters in both channels. The data provide a monitor of the UVIS/IR flux stability as a function of time and wavelength as well as check for the presence of possible contaminants.

Description of the observations: The target for both channels in Cy 19 is the white dwarf spectrophotometric standard GRW+70d5824, two orbits per iteration. The chosen cadence will be deliberately out of phase with the monthly anneal procedures in order to sample the phase space. Each iteration of the monitor will obtain sub-array observations of the standard star in a variety of filters in both UVIS and IR. The former will be done with the major UV and several visible filters, in both chips, as well as the G280 grism on chip2 for a contamination measurement. IR channel imaging will be done with the IR G102 and G141 grisms along with as many IR filters as will fit within the remaining visibility period. Observations will be acquired every 5 weeks.

CAL-12699 WFC3 Photometric Calibraiton & Calibration Flux Ladder
Number of external orbits: 16 **Number of internal orbits:** 0

Goals: Increase accuracy of zeropoint measurements in key filters, monitor sensitivity trends in the UVIS and IR channels, improve characterization of photometric uncertainties at several count rates, and monitor sensitivity trends and provide high accuracy color corrections. This continues the Cycle 17 and Cycle 18 photometric programs in which we observe WD standard stars GD153, GD71, G-type P330E and M-type VB8 through the key subset of filters.

Develop the calibration flux ladder from the brightest standard star(s) through faintest standards to improve the WFC3/IR absolute photometric calibration and cross-calibration of the observing modes now available for both grism and direct imaging, i.e. point and stare, and, spatial scanning. For the IR channel, this extends and builds upon the Cycle18 program, 12336, by observing stars fainter than 9 mag to calibrate linearity of the new modes. Program 12336 observed Vega, an absolute flux standard, as well as 5th magnitude stars with the two IR grisms in spatial scanning mode in the -1^{st} order and the $+1^{st}$ order. Critical is wavelength and flux calibration of the -1^{st} order, which has only been observed once, during SMOV (11522). Spatial scans are carried out at various scan rates but at constant counts per pixel

Description of the observations: To minimize uncertainties due to models, and drive absolute calibration to $< 0.5\%$ we will perform:
Direct imaging of the the 4 standard stars (UVIS and IR): 4 orbits
Spatial scanning of $9 < V < 13$ mag stars: grism and imaging (IR): 4 orbits
Direct imaging for $V > 14$ mag (IR and UVIS) : 8 orbits

At each brightness level we use two blue stars and two red(-ish) stars. The source list consists of stars observed with STIS, ACS, NICMOS, SPITZER/IRAC, and JWST calibration standards. Brightness span the range from $V \sim 9$ mag to $V = 18$ mag. IR and UVIS observations for the bright stars can be acquired in one orbits each, the faint stars require 2 orbits, one each for UVIS and IR observations. Observations are paced throughout the cycle at regular intervals, roughly monthly.

Targets: Standard suite: P330E, VB8, GD71 and GD153
A-type stars: HD165459 (A4V), 1732526 (A4V), 1740346 (A6V), 1743045 (A8II), 18032271 (A2V), 1805292 (A4V), 1812095 (A5V)
G-type stars: HD209458 (G0V), P041C (G0V), P177D, SNAP-2 (GO-5)
Other: 2M0036+18 (L3.5), 2M0559-14 (T5), KF06T2 (K1.5III)

CAL-12700 Extending the Range & Precision of the Count Rate non-Linearity
Number of external orbits: 4 **Number of internal orbits:** 0

Goals: Determining the count rate non-linearity (CRNL) of a HgCdTe device is critical in order to extend the zeropoints measured with bright stars to the much fainter science level fluxes. We propose to observe 2 more fields of asterisms to fill in the flux range of $14 < H < 17$, a gap between previous asterism and cluster data. We also propose to improve the precision of the cluster calibration by comparison of the CCD and near-IR data at overlapping wavelengths.

Description of the observations: We will observe 10 stars in 2 filters per orbit in 2 asterisms. The asterisms contain stars a few mag fainter than in the CY18 program (Riess 2011), yet still be well monitored in the literature to avoid known variability. The comparison between 2MASS and WFC3-IR calibrates the CRNL.

CAL-12701 WFC3 UVIS & IR PSF Wings
Number of external orbits: 6 **Number of internal orbits:** 0

Goals: Measure encircled energy of a PSF as a function of radius at 5 locations on each detector with an accuracy of 1% for radii $r > 0.2$ arcsec for UVIS and $r > 0.35$ arcsec for IR channel. Results will be compared to SMOV and CY17 to check for image stability.

Description of the observations: A moderately bright isolated star (GD153) will be observed at 5 locations (near the detector center and corners) in one filter per detector(F275W and for UVIS, and F098M for IR). Deep, saturated full frame images will be obtained at each pointing to permit evaluation of the wings at radii $r > 5$ arcsec. Shorter exposures UVIS sub-array images will be obtained at each pointing with a series of increasing exposure times, to be combined with the saturated full frame images to construct very high S/N PSFs (On the IR pre-saturation reads make additional exposures unnecessary).

CAL-12702 WFC3/IR Grisms: Flux/trace calibration and stability
Number of external orbits: 8 **Number of internal orbits:** 0

Goals: Verify and refine the flux calibration of the IR Grisms G102 and G141.

Description of the observations: We will observe GD71/P330E in 16 different positions using the G102 and G141 IR Grisms. The pointings will repeat 4 previously observed positions and add 12 new positions to better sample the 2D variability wavelength dispersion relations of the 2 Grisms. This is a continuation of programs 11936, 12357, and 12358.

CAL-12703 WFC3/IR Grisms: Wavelength & stability calibrations
Number of external orbits: 8 **Number of internal orbits:** 0

Goals: Verify and refine the wavelength calibration of the IR Grisms G102 and G141.

Description of the observations: We will observe VY-22 in 16 different positions using the G102 and G141 IR Grisms. The pointings will repeat 4 previously observed positions and add 12 new positions to better sample the 2D variability wavelength dispersion relations of the 2 Grisms. This is a continuation of programs 11937, 12355 and 12356.

CAL-12704 WFC3/UVIS Grism: Flux calibration
Number of external orbits: 3 **Number of internal orbits:** 0

Goals: Derive the flux calibration for the Grism G280 over the whole UVIS channel.

Description of the observations: We will observe GD-71 in 10 different positions (5 per chip) using the G280 UVIS Grism. For each chip we will repeat 3 pointings already observed in Cycle 18. These poinitings are crucial because they show both the $+1^{st}$ and -1^{st} orders. The 2 new pointings will allow us to better sample the 2D variability-wavelength dispersion relations of the Grism. The final sampling (Cycles $18+19$) will be 3×3 per CHIP.

CAL-12705 WFC3/UVIS Grism: Wavelength & stability calibrations
Number of external orbits: 3 **Number of internal orbits:** 0

Goals: Verify and refine the wavelength calibration of the UVIS Grism G280.

Description of the observations: We will observe WR14 in 10 different positions (5 per chip) using the G280 UVIS Grism. For each chip we will repeat 3 pointings already observed in Cycle 18. These poinitings are crucial because they show both the $+1^{st}$ and -1^{st} orders. The 2 new pointings will allow us to better sample the 2D variability-wavelength dispersion relations of the Grism. The final sampling (Cycles $18+19$) will be 3×3 per CHIP. This is a continuation of program 12359.

CAL-12706 WFC3/UVIS FlareWavelength Dependence
Number of external orbits: 2 **Number of internal orbits:** 0

Goals: We will measure the relative strength of the 4 WFC3/UVIS ghost reflections with respect to the primary source as a function of wavelength.

Description of the observations: We will place a bright star in the lower left corner of amp D in a suite of filters and measure the 4 internal ghost reflections in a suite of filters to measure the wavelength dependence of the window ghosts. Full frame images are required to place all 4 ghosts on the detector, but they will be binned 3×3 to optimize observing time.

We require $108e^-$ in the primary source to give $\sim 100e^-$ per pixel in the faintest ghost.

To achieve this, a bright A0V star ($V = 8$) will be observed using a short narrow band exposure plus a long broadband exposure. A two point (fine) dither will be executed at each step to reject cosmic rays. Seven narrow plus seven broadband filters will fit in a single orbit.

CAL-12707 WFC3/UVIS Spatial Stability

Number of external orbits: 10 **Number of internal orbits:** 0

Goals: We will measure the spatial stability of a standard star in a number of positions across the detector to verify the inflight corrections to the ground flats.

Description of the observations: Inflight corrections to the UVIS ground flats have proved more complex than expected, with a several large internal window reflections in the ground flats and strong spatial variations in the PSF over the detector. To to validate the accuracy of the latest flats, derived from aperture photometry of dithered stellar observations, we will move the spectrophotometric standard G191-B2B over 50 positions across the detector in 4 the broadband filters F275W, F438W, F606W, & F814W. A two point (fine) dither is executed at each position to reject cosmic rays. We will step across each of the 4 flares, across the region in amp D where the chip is 3.5 microns thinner and carefully sample the upper left corner which moves strongly in and out of focus with telescope breathing.

CAL-12708 WFC3/IR Spatial Stability

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

Goals: We will measure the spatial stability of a standard star in a number of positions across the detector to verify the inflight corrections to the ground flats.

Description of the observations: As for the UVIS channel we will validate the accuracy of the latest flats and the stability of our flux calibration by moving the spectrophotometric standard WD 1057 + 719 ($V = 14.68$ mag) across the array. In one orbit we can observe the WD 1057 + 719 in 3 broadband filters (F098M, F125W & F160W) in 8 different positions, for a total of 32 different positions.

CAL-12709 WFC3 UVIS & IR Dark Earth Flats

Number of external orbits: 0 **Number of internal orbits:** 50

Goals: Flat-fields will be obtained by observing the dark side of the Earth during periods of full moon illumination.

Description of the observations: Earth flats provide a diffuse source that can be used to define on-orbit flat-field corrections to the WFC3 flats. When using the sunlit Earth the wide band filters saturate at even the shortest possible exposure times and cannot be used to generate flat-fields directly. Pathfinder programs 11914 and 11917 have shown the usefulness of taking moonlit Earth flats and the addition of the DARK-EARTH calibration target in APT has increased the scheduling of exposures (see timeline) making the Earth flats program suitable for CY19. In 2 orbits (1500 s total exp time for these), we get $10^4 e^-/pix$ in F606W. Bill Januszewski. has scheduled $\sim$ 4 orbits/month for dark Earth flats and estimates thats nearly the maximum attainable (i.e. $\sim 48/year$).

The observations will consist of full-frame streaked WFC3 UVIS imagery. UVIS filters: F469N, F606W, F656N, F814W, FQ906N + F336W. IR filters: F105W, F110W, F125W, F140W, F153M, F160W, F164N, F167N.

CAL-12710 WFC3/UVIS Bright Earth Flats
Number of external orbits: 0 **Number of internal orbits:** 20

Goals: We will obtain sky flats in the UV using the bright Earth to fully illuminate the detector. These will allow validation of the L-flat solutions obtained from dithered stellar observations and verification that the wavelength interpolation of these solutions is accurate for filters which were not directly observed.

Description of the observations: Below $\sim$ 4000Å the Earth is a uniform source of diffuse light due to the high optical depth above the cloud layer. For ACS, the HRC F344N and F330W pipeline flats were derived entirely from Earth flats (Bohlin & Mack 2003, Bohlin & Mack 2005). For WFC3 UVIS, red leaks below ~F275W will be contaminated by out of-band light. Thus we propose to observe with the UV filters F275W, F280N, F336W, F343N, F373N, F390M. Bright Earth flats are much easier to schedule than moonlit flats. The ACS programs were easily scheduled if kept to $\sim$ 20 min. With 2 exposures each, all 6 filters will fit within a single orbit. The success rate is $\sim$ 50% for ACS/HRC/F330W, so we propose 20 orbits to ensure several images with adequate illumination are obtained in each filter.

CAL-12711 WFC3/UVIS Internal Flats
Number of external orbits: 0 **Number of internal orbits:** 20

Goals: Monitor the stability of the UVIS filters.

Description of the observations: Observe internals in all the UVIS filters once early in the Cycle. We will use 3 orbits with D2 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 6 times over the cycle for a total of 6 orbits. Late in the cycle we will repeat the 3 orbits with the D2 lamp.

CAL-12712 WFC3/IR Internal Flats

Number of external orbits: 0 **Number of internal orbits:** 33

Goals: Monitor the stability of the IR pixel-to-pixel sensitivity.

Description of the observations: Observe internals in all the IR filters once in the middle of the Cycle (18 orbits for the Tungsten lamp). Observations in the 5 filters F105W, F110W, F125W, F140W and F160W with the tungsten lamp will be repeated 5 times over the cycle for a total of 15 orbits. Both internal and external observations indicate that IR flat-fields are stable to the $\leq 1\%$ level.

CAL-12713 Spatial Scanned L-flat Validation Pathfinder

Number of external orbits: 7 **Number of internal orbits:** 0

Goals: Using spatial scans of a bright star or double star, validate L-flats generated by the standard method of observing star clusters.

Description of the observations: We will observe a bright double star, e.g. HD 80606 ($V = 9$ each, separation = 20 arcsec) with the boustrophedonically scanned HST[1] in filters for which traditional L-flats using star clusters exist. We allocate six orbits for UVIS and two for IR. The advantage of a double star compared to a single star, is that the differential photometry of the one star w.r.t. the other star is independent of variations about the nominal scan rate. To take advantage of that, we plan to observe the double star first scanning fast in X with large steps in Y, then 90 degrees to that, and then combining all the differential magnitudes, binned on a regular 8×8 array, and then we will convert those from slopes to a surface much like one converts from a Hartmann wavefront sensors slopes

[1]Boustrophedonically scanned HST means shaped like the ox plows, or in modern experience, like the coils on the back of a refrigerator. Each round-trip lap will take 1 min, and we want 8 laps per exposure, and two exp/filter, so we should be able to complete two filters per orbit.

to a wavefront. Filters: F225W, F350LP, F475W, F656N, F606W, F850LP, F953N, F125W, F160W.

CAL-12714 UVIS & IR Geometric Distortion
Number of external orbits: 2 **Number of internal orbits:** 0

Goals: Establish the time dependency of UVIS and IR skews. Monitor the optical and mechanical stability of the UVIS detector and IR array. Continue the multi-cycle study of the geometric distortion time-dependency.

Description of the observations: The globular cluster ωCen will be observed this winter in the F606W (UVIS) and F160W (IR) filters at different roll angles. For both the channels three exposures will be acquired in a sequence of off-nominal roll-angles with steps of +15, 0, and -15 degrees. So far there is no evidence for a secular change in the UVIS nor IR scale over 2 years of observations.

CAL-12784 Characterization of UVIS Traps via Charge-Injected Biases
Number of external orbits: 0 **Number of internal orbits:** 90

Goals: Identify and characterize the traps in the UVIS CCDs responsible for the charge losses.

Description of the observations: In each orbit we will acquired 2 line 17 and 2 line 25 CI biases. This set up will allow us to identify all the traps in the UVIS channel. Preliminary analysis indicates that every month $\sim$ 10 traps per column appear. By repeating the observations every 4 days we will monitor the growth with time of the number of traps. A total of 90 internal orbits is required.

References

Baggett, S., & Borders, T. 2010, "WFC3 SMOV Proposal 11808: UVIS Bowtie Monitor", WFC3-ISR 2009-24

Bohlin & Mack 2003, "NUV Earth Flats", ACS-ISR 2003-02

Bohlin & Mack 2005, "Earth Flats", ACS-ISR 2005-12

Deustua, S., et al. 2009, "WFC3 Cycle 17 Calibration Program", WFC3-ISR 2009-08

Deustua, S. 2011, "WFC3 Cycle 18 Calibration Program", WFC3-ISR 2011-14

Dressel, L. 2011, "Wide Field Camera 3 Istrument Handbook, Version 4.0" (Baltimore:STScI)

Gilliland, L.R. 2004, “ACS CCD Gains, Full Well Depths, and Linearity up to and Beyound Saturation”, ACS-ISR 2004-01

McCullough, P. 2011, “Geometric Model of UVIS window ghosts in WFC3”, WFC3-ISR 2011-17

Kozhurina-Platais, V., Hilbert, B., Martel, A., & McCullough, P. 2009, “WFC3/UVIS CTE -EPER Measurement”, WFC3-ISR 2009-10

Kozhurina-Platais, V., Hilbert, B., Baggett, S., & Petro, L. 2011, “WFC3/UVIS CTE-EPER Measurement: Cycle 17 & 18”, WFC3-ISR 2011-17

Rajan, A. et al. 2010, “WFC3 Data Handbook”, Version 2.1, (Baltimore: STScI)

Riess, A.G. 2011, “An Independent Determination of WFC3-IR Zeropoints and Count Rate Non-Linearity from 2MASS Asterism”, WFC3-ISR 2011-15