WFC3 Cycle 23 Calibration Plan

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(Revised 10/2/15)

WFC3 Usage

WFC3 is extremely successful because of its:

- panchromatic capabilities (wavelength range from 2000 Å to 1.7 μm);
- multiple observing modes (imaging, spectroscopy, spatial scans, variety of readout modes, 80 different filters)
- Both channels continue to be very popular.

Percentage of Exposures for WFC3 Channels in the Past Cycles

	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%
Cycle 22	40%	60%	85%	15%
Cycle 23	**28%**	**72%**	**74%**	**26%**

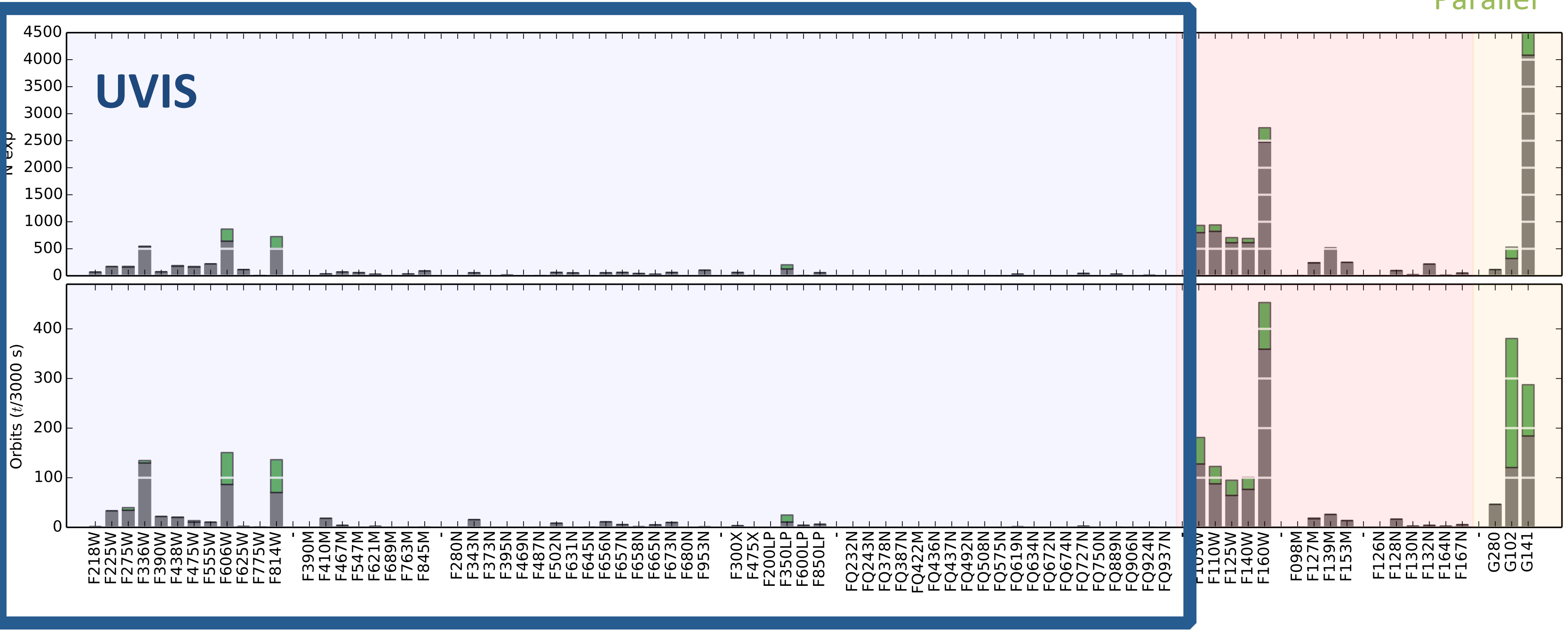
WFC3 Usage with time

HST Cycle	GO Programs* % of HST orbits	Calibration** # External orbits	Calibration** # Internal orbits
CY17	46%	256	>2000
CY18	42%	134	1719
CY19	49%	125	1497
CY20	56%	83	1833
CY21	54%	98	1907
CY22	48%	114	1620
CY23	**46%**	**98**	**1619**

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

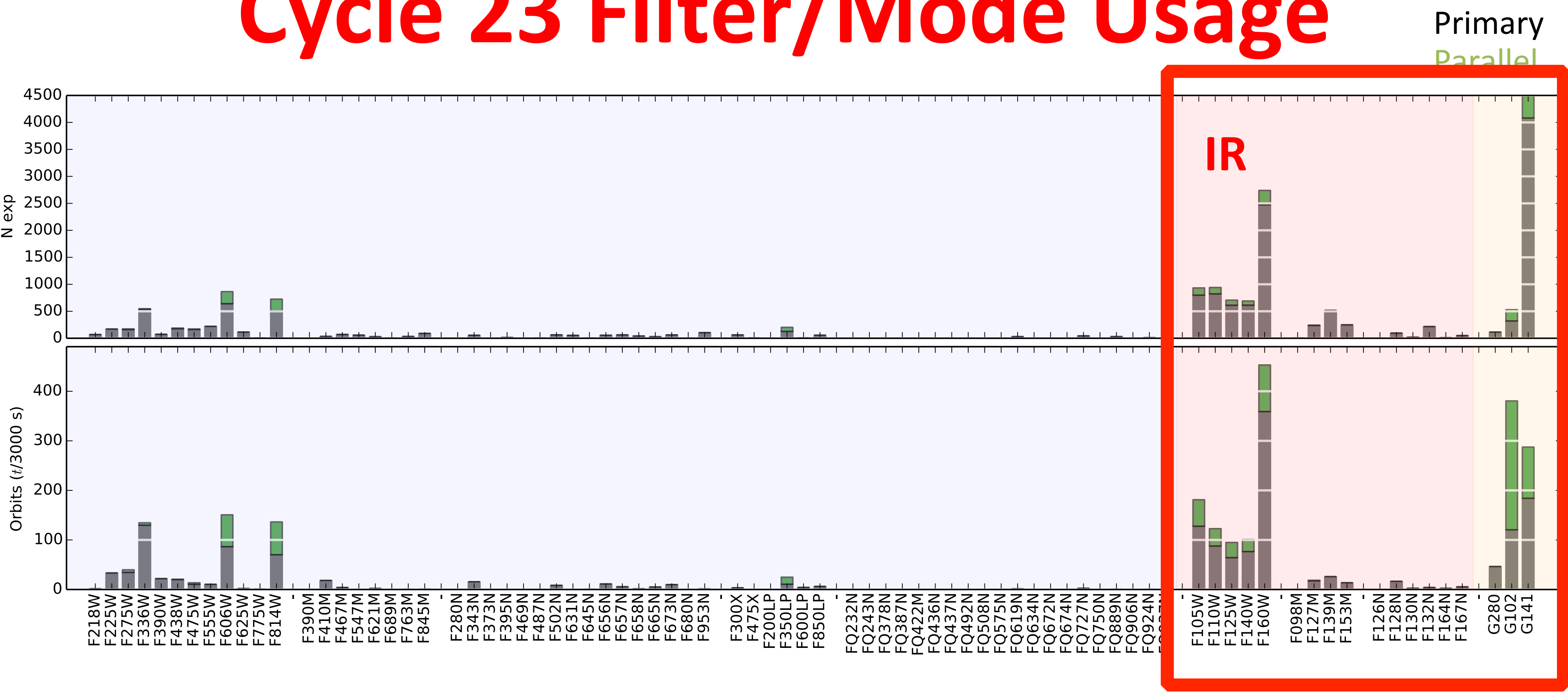
Cycle 23 Filter/Mode Usage

Primary
Parallel



- 43% of UVIS time is used to observe in the near UV (λ < 4000 Å, incl. G280)
- 47% of UVIS exposures use post-flash
- 42 out of the 62 UVIS filters are used in CY23
- 1.1% of UVIS time is for spatial scan
- 6.6% of UVIS time is with G280 (139 ks)

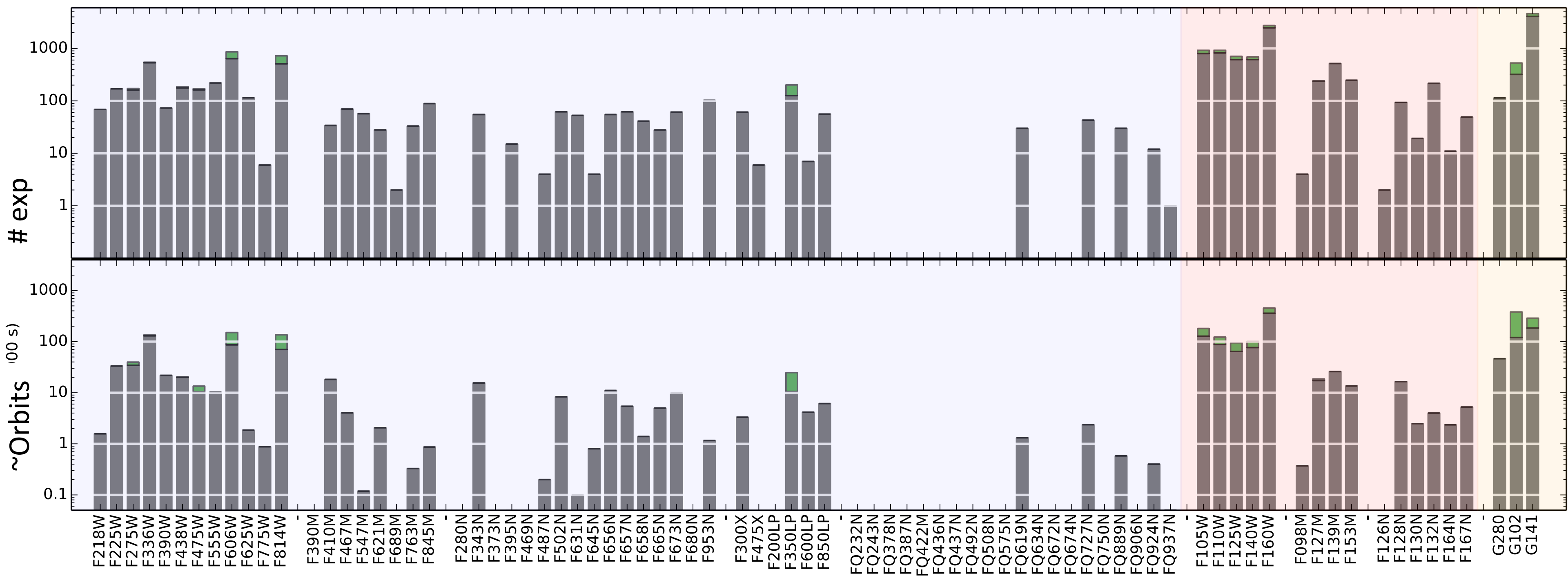
Cycle 23 Filter/Mode Usage



- 40% of the IR exposures/time use GRISMS
- **All 17 IR filters and grisms are used**
- 20% of the exposures uses spatial scan (6% of IR time)

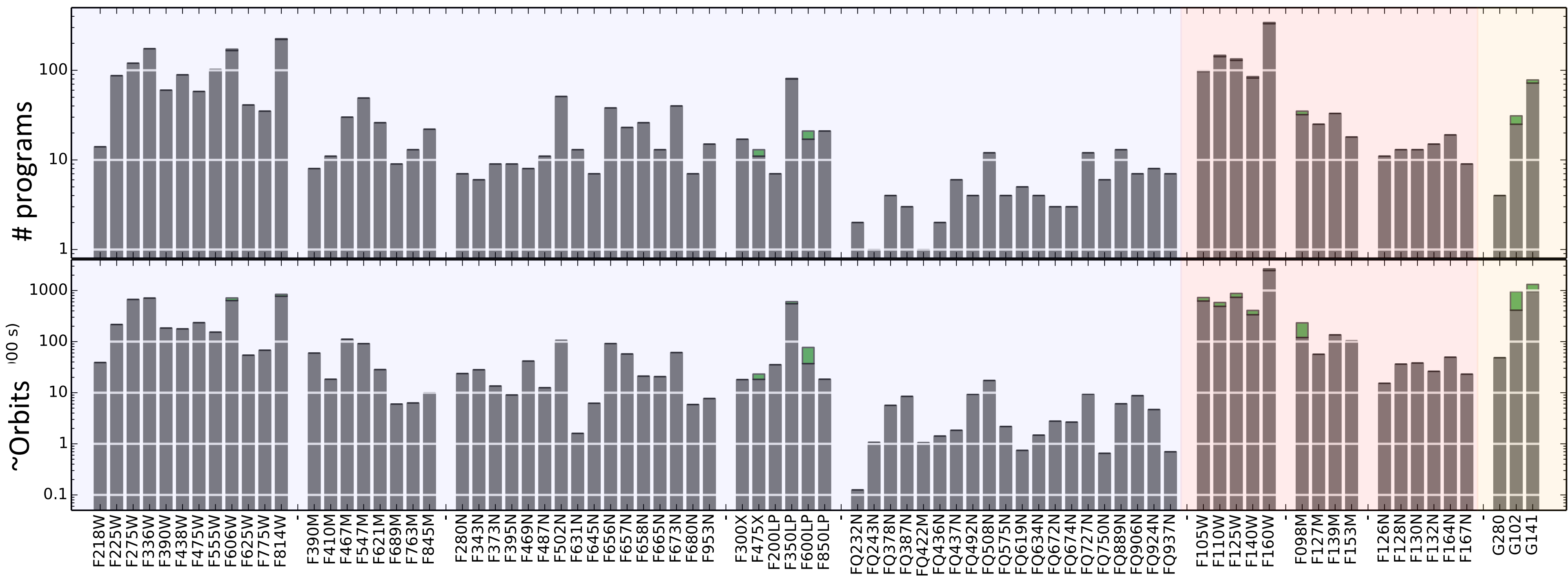
Cycle 23 Filter/Mode Usage

Primary
Parallel



Cycle 23 usage comparable to overall usage.

Past Filter Usage, SM4–8/15/15



Cycle 23 usage comparable to overall usage.

CY22 Approved Program

Program Title	Ext. Orbits	Int. Orbits		Program Title	Ext. Orbits	Int. Orbits
UVIS anneal	0	85		WFC3/UVIS contamination monitor	18	0
UVIS bowtie monitor	0	130		UVIS Shutter Characterization	3	1
UVIS CCD daily monitor (darks & biases)	0	637		Photometric repeatability of scanned direct imaging	4	0
UVIS CCD un-flashed monitor	0	140		WFC3 UVIS & IR photometry	21	0
UVIS post-flash monitor	0	48		WFC3 IR observations of red CALSPEC stars	3	0
UVIS CCD gain stability	0	18		Low count-rate cross-calibration of WFC3 F110W and NIC2 F110W	1	0
IR dark monitor	0	95		WFC3 IR grisms wavelength calibration stability and calibration	4	0
IR linearity monitor	0	9		WFC3 IR grisms flux/trace calibration stability and calibration	4	0
IR gain monitor	0	16		WFC3 UVIS grism wavelength calibration stability and calibration	2	0
UVIS CTI monitor (EPER)	0	12		WFC3 UVIS grism flux calibration	2	0
UVIS CTE monitor (star cluster)	6	0		UVIS Pixel-to-Pixel QE Variations via Internal Flats Monitor	0	51
WFC3/UVIS CTE in subarrays	0	42		UVIS internal flats	0	13
Characterization of UVIS traps with CI	0	36		IR internal flats	0	18
Refining the persist. model in the IR detector	12	12		CSM monitor with earth flats	0	200
Short term persistence	3	3		Astrometric Validation of WFC3/UVIS filters	18	0
Persist. after worst actors	0	50		High precision calibration of WFC3/UVIS geometric distortion (CAL-13929)	10	0
Persist. after non-scanned grism obs.	3	4		SPARS5 verification (September 2015, CAL-14328)	1	18

CY22 Total external orbits=115 Total internal orbits=1634

CY22 Approved Program

Program Title	Ext. Orbits	Int. Orbits		Program Title	Ext. Orbits	Int. Orbits
UVIS anneal	0	85		WFC3/UVIS contamination monitor	**ISR 2014-20 (Gosmeyer)**	
UVIS bowtie monitor	0	130		UVIS Shutter Characterization	**ISR 2015-12 (Sahu)**	
UVIS CCD daily monitor (darks & biases)	**AAS 2014 (Bourque)**			Photometric repeatability of scanned direct imaging	4	0
UVIS CCD un-flashed monitor	0	140		WFC3 UVIS & IR photometry	**AAS 2014 (Gosmeyer)**	
UVIS post-flash monitor	0	48		WFC3 IR observations of red CALSPEC stars	3	0
UVIS CCD gain stability	**ISR 2015-05 (Gunning)**			Low count-rate cross-calibration of WFC3 F110W and NIC2 F110W	1	0
IR dark monitor	0	95		WFC3 IR grisms wavelength calibration stability and calibration	**ISR 2015-10 (Bohlin)**	
IR linearity monitor	**ISR 2014-17 (Hilbert)**			WFC3 IR grisms flux/trace calibration stability and calibration	**AAS 2015 (Pirzkal)**	
IR gain monitor	**AAS 2015 (Gunning)**			WFC3 UVIS grism wavelength calibration stability and calibration	**ISR 2015-X (Pirzkal), in prep, some products delivered**	
UVIS CTI monitor (EPER)	0	12		WFC3 UVIS grism flux calibration		
UVIS CTE monitor (star cluster)	**ISR 2015-03 (Baggett)**			UVIS Pixel-to-Pixel QE Variations via Internal Flats Monitor	**ISR 2014-18 (Gunning)**	
WFC3/UVIS CTE in subarrays	0	42		UVIS internal flats	0	13
Characterization of UVIS traps with CI	0	36		IR internal flats	**ISR 2015-11 (Ryan)**	
Refining the persist. model in the IR detector	**ISR 2015 (Long)**			CSM monitor with earth flats	**ISR 2014-21 (McCullough)**	
Short term persistence	3	3		Astrometric Validation of WFC3/UVIS filters	**ISR 2015-02 (Platais)**	
Persist. after worst actors	0	50		High precision calibration of WFC3/UVIS geometric distortion (CAL-13929)	**Riess et al.2014 *ApJ*, 785, 161**	
Persist. after non-scanned grism obs.	3	4		SPARS5 verification (September 2015, CAL-14328)	1	18

CY22 Total external orbits=115 Total internal orbits=1634

CY23 Proposed Calibration Program

Category	Program Title	Ext. Orbits	Int. Orbits
UVIS CCD	UVIS anneal	0	**79**
UVIS CCD	UVIS bowtie monitor	0	130
UVIS CCD	UVIS CCD daily monitor (darks & biases)	0	637
UVIS CCD	UVIS CCD un-flashed monitor	0	135
UVIS CCD	UVIS post-flash monitor	0	**60**
UVIS CCD	UVIS CCD gain stability	0	18
IR Detector	IR dark monitor	0	95
IR Detector	IR linearity monitor	0	10
IR Detector	IR gain monitor	0	16
CTE	UVIS CTI monitor (EPER)	0	12
CTE	UVIS CTE monitor (star cluster)	**8**	0
Persistence	Characterization of UVIS traps with CI	0	36
Persistence	IR persistence: Amplitude Variations	0	**60**
Persistence	IR Persistence: Improve the Position Dependent Model	**16**	**48**

Category	Program Title	Ext. Orbits	Int. Orbits
Photometry	WFC3/UVIS contamination monitor	**15**	0
Photometry	UVIS Shutter Characterization	3	1
Photometry	WFC3 UVIS & IR photometry	**11**	0
Grism spectroscopy	WFC3 IR grisms wavelength calibration stability and calibration	4	0
Grism spectroscopy	WFC3 IR grisms flux/trace calibration stability and calibration	4	0
Grism spectroscopy	WFC3 UVIS grism wavelength calibration stability and calibration	**1**	0
Grism spectroscopy	–1st grism order calibration in IR grisms	**2**	0
Flats	UVIS Pixel-to-Pixel QE Variations via Internal Flats Monitor	0	51
Flats	UVIS internal flats	0	13
Flats	IR internal flats	0	18
Flats	CSM monitor with earth flats	0	200
Astrom	Astrometric calibration of **all remaining** UVIS filters	**30**	0
Astrom	Time Dependence of X-CTE & Astrometry	**4**	0

CY23 Total external orbits=98 Total internal orbits=1619

Characterization of IR Traps (“Persistence”)

16 external and 92 internal orbits will be used to:

1. 60 internal orbits to improve the “persistence flat”. – New program!

2. 16 external and 32+16 internal orbits to improve the exposure-time/position-dependent persistence model. External orbits on Omega Cen needed to maximize dynamic range of pixel illumination, from zero to >> saturation. 16 additional internal orbits to characterize “burps”. – New program!

IR Persistence: Amplitude variations

Number of External Orbits: 0 **Number of Internal Orbits:** 60

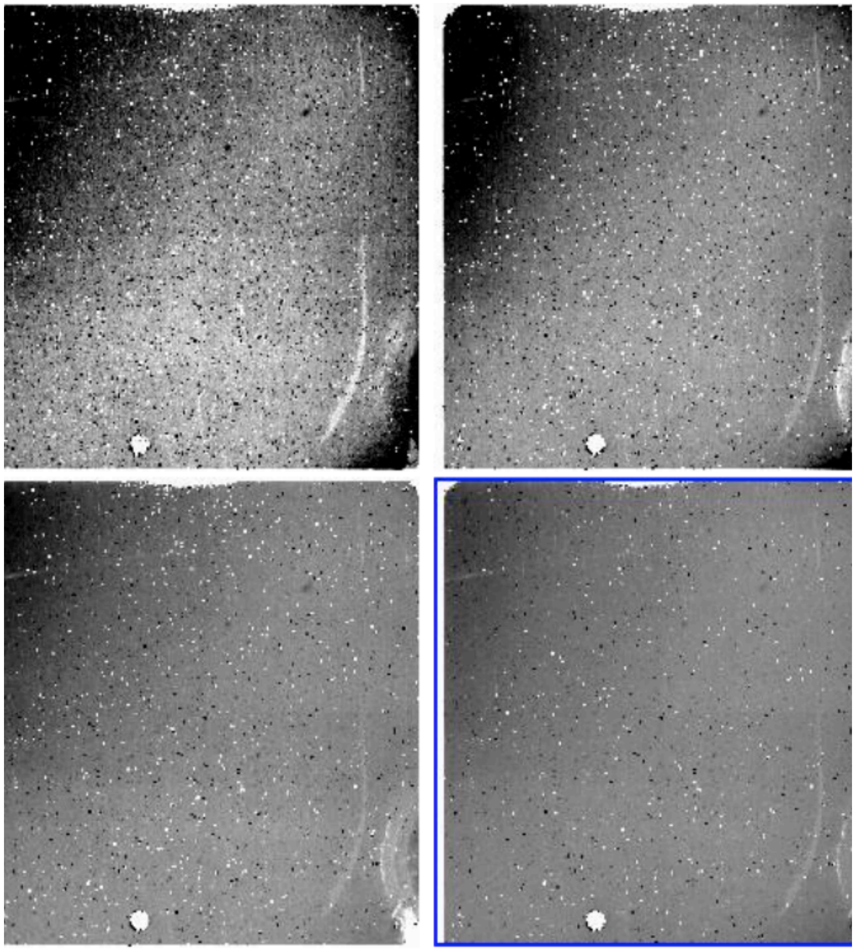
Goals: The current persistence model treats spatial variations as an amplitude variation across the detector and is implemented with a persistence "flat". This proposal seeks to improve the current persistence model by obtaining data that would enable us to create persistence ``flats'' for a variety exposure times and fluence levels.

Current status: The current persistence "flat" was constructed from a heterogeneous set of observations similar to those described below. There are (10–25%) differences between flats constructed with different subsets of the data. There is not enough data, however, to explore these data in a systematic fashion.

Description of the Observations: The observations will consist of a series of Tungsten lamp exposures followed by darks. Each visit requires 3 full internal orbits. We would use different filters to achieve 5 different fluence levels at each exposure level. We propose to test at 4 different exposure lengths. Thus the program would require 60 full internal visits.

Correction Flats

- Four correction flats constructed using darks after Tungsten/F105W filter exposures of 102 (upper left), 152 (upper right), 302 (lower left), and 2002 s (lower right)
- All of the images are scaled from 0.7 (white) to 1.3 (black)
- The shorter exposure/low fluence flats have larger spatial variation from quadrant 1 (high) to quadrant 3 (low)
- Differences reflect a combination of exposure time and fluence
- The proposed program will break this degeneracy



IR Persistence: Development of a position-dependent model

Number of External Orbits: 16 **Number of Internal Orbits:** 48

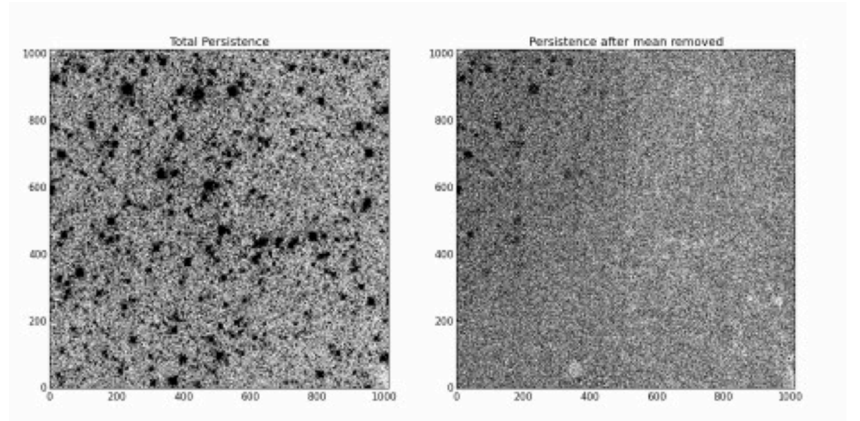
Goals: The purpose of this proposal is to develop the first full spatially dependent model of persistence for the WFC3 IR detector.

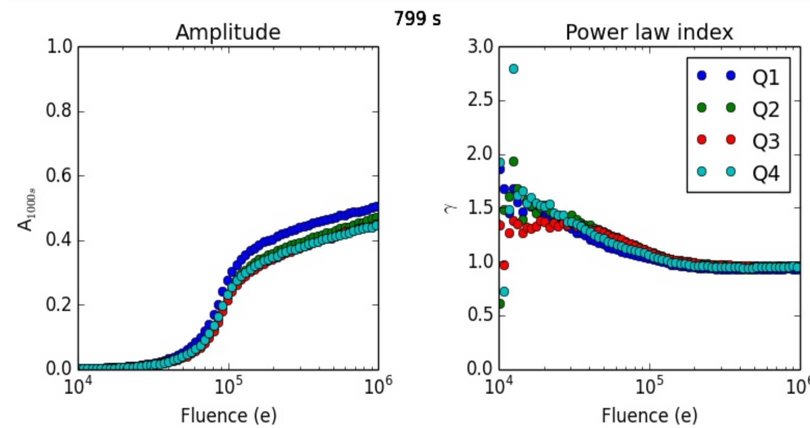
Current status: The current data we have from the Cycle 22 program allows us to estimate the spatially averaged persistence and to see variations on a quadrant by quadrant basis, that is, we can make a 2×2 grid of models for each exposure time we have data for with a single visit. This is insufficient to create an interpolated model of persistence across the detector.

Description of the Observations: The observations will consist of a series of exposures of ω Cen followed by darks. Each visit requires 1 external and 2 full internal orbits. To obtain sufficient data to model the persistence in a 4×4 grid at one exposure level requires 4 visits (so that we have the same statistics in a 4×4 grid as a 2×2 grid now. We propose to carry out this study at 4 exposure times—152, 302, 702 and 1199 s—for a total of 16 external orbits (32 internal).

Spatial model: 2×2 → 4×4

- In contrast to experiments with the Tungsten lamp, experiments with external target measure persistence at a large range of fluence levels simultaneously (See upper figure)
- Lower figure shows example of persistence as measured in darks after a single ω Cen exposure in each of 4 quadrants (500×500 pixels).
- The main variation is in *A* although there hints of changes in γ as well (time decay).
- The proposed observations, which will involve 4 visits with the same exposure time (offset), will allow one to create similar models on a scale 250×250 pixels
- One can interpolate by analyzing at offset positions.



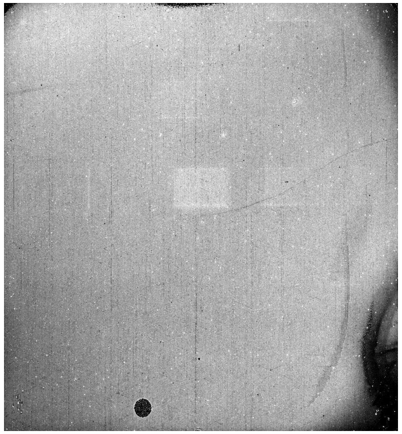


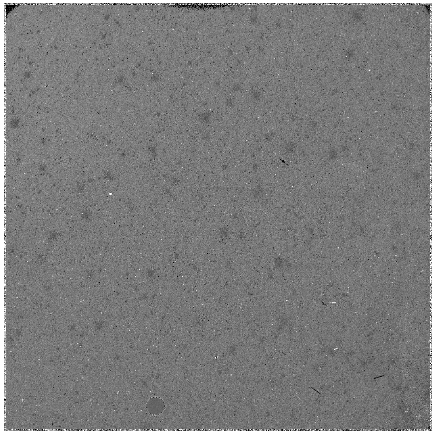
$$P(f,t) = A(f)\ (t/1000)^{-\gamma(f)}$$

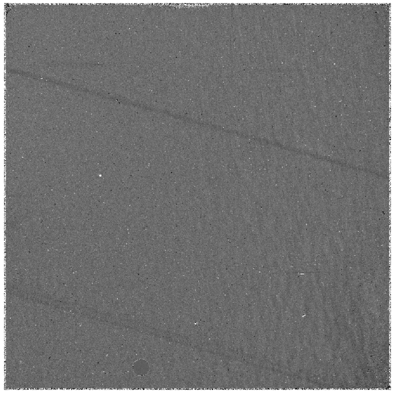
where f is the fluence and
t is the time since the stimulus

Characterizing stimulated persistence (“burps”) - 16 additional internal orbits accompanying prev.

- In addition to normal persistence, the IR detector shows persistence-like after images during and after Tungsten lamp flats (of more than half full well)
- These “burps” are bright compared to that expected from normal persistence
- No attempt to systematically characterize this phenomenon has occurred
- Characterization would consist of a controlled exposure of a dense star field followed by visits consisting of a series of darks, a Tungsten flat and then another series of darks
- We propose to add an extra internal orbit (darks +flat+darks) to the program to create a spatially dependent model as a first attempt to systematically characterize this problem
- We would separate this (full) internal orbit by **TBD** hours from the Omega Cen observation and vary the fluence level in the internal flat
- Goals (not to develop a complete model, but) to:
  – Quantify the amount of extra “persistence” in the post flat images
  – Determine how long the “extra” persistence lasts
  – Determine the fluence required to stimulate the extra persistence
  – Estimate the effect on WFC3 photometry







About 30% of high fluence flats show “burps” from stimulus sometimes more than 24 hours earlier.

Astrometric Calibration

We request 34 external orbits for the following:

1. 30 external orbits will be used to determine the full geometric distortion solution for **all** the WFC3/UVIS filters for which this hasn't yet been done. Short accompanying F606W exposures in each visit to monitor (lack of) time evolution. – New Program!

2. 4 external orbits will be used to measure time evolution of the high precision geometric distortion solution derived from spatial scans. – Decreased from CY22

Astrometric Calibration of Broad, Medium, Narrow and Quad UVIS Filters

Number of external orbits: 30 **Number of internal orbits:** 0

Goals:

- Astrometric calibration for the geometric distortion of **all** UVIS filters with < 0.1 pixel precision:
    - High order polynomial coefficients as the reference files (*IDCTAB*) to be used in OPUS and DrizzlePac
    - Non-polynomial filter dependent component of distortion as the reference file (*NPOLFILE*) to be used in OPUS and DrizzlePac
- Monitoring the optical & mechanical stability of the WFC3/UVIS using the F606W filter, which is the adopted reference filter for studying of multi-cycle time-dependency of the geometric distortion.

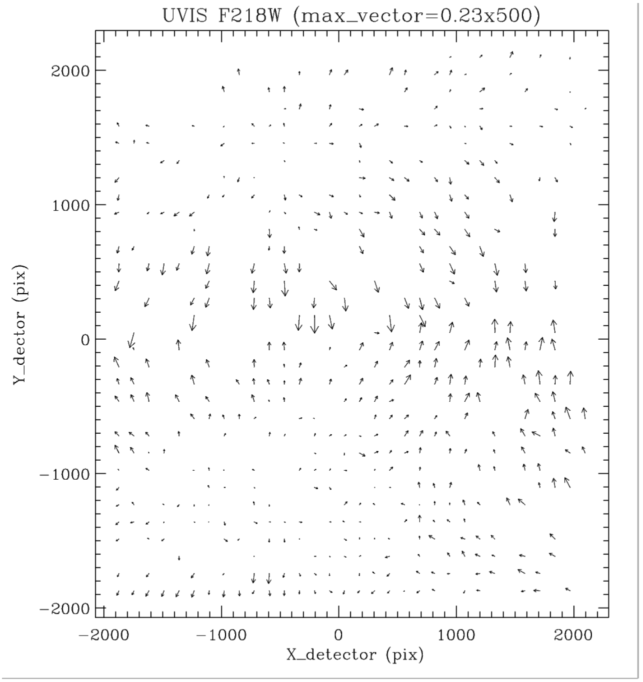
Description of observations:

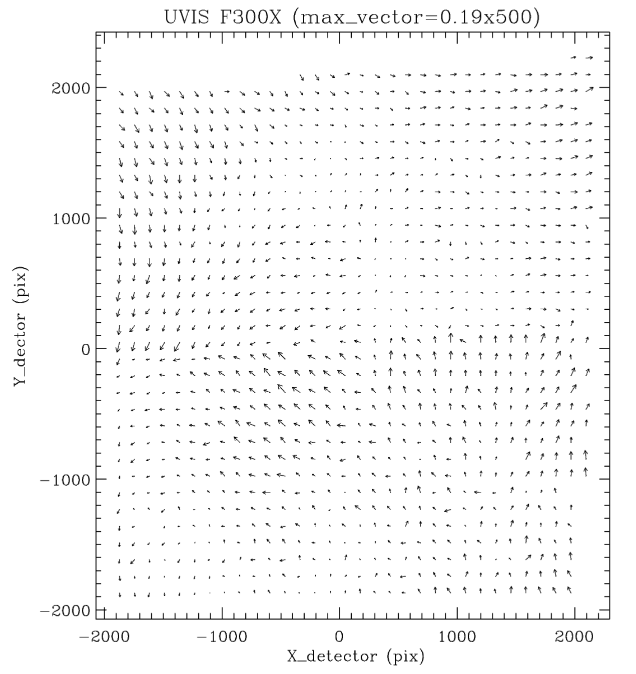
- Observations of globular cluster omega Cen through F606W, 4 Broad, 7 Medium, 10 Narrow, and 3 Quad UVIS filters in order to use the HST standard astrometric catalog (2005–2006; J. Anderson)
- Single exposure in F606W followed by 5 exposures for each filter with a ±40” dither pattern

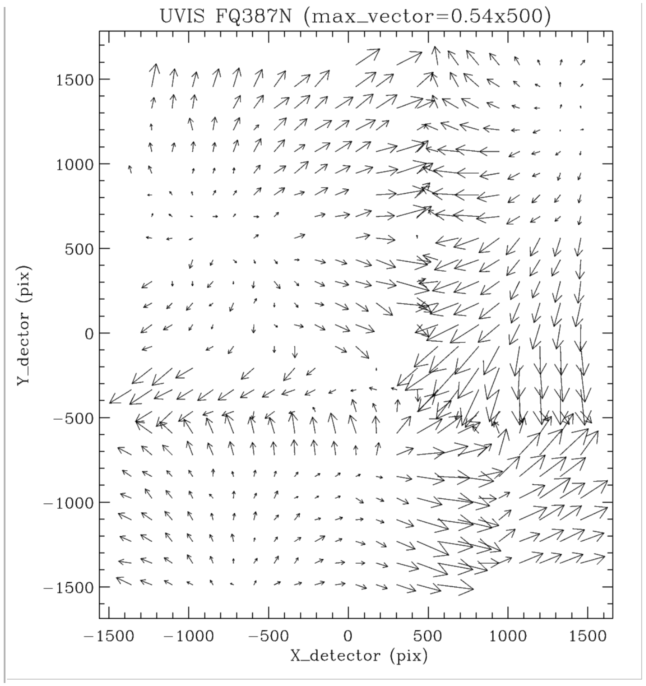
Lessons from Cy22 (CAL-14031):
Astrometric Verification of Medium, Narrow and QUAD WFC3/UVIS Filters

Un- calibrated Filters - F218W, F300X, FQ387N *w.r.t* F606W: Results from DrizzlePac/TweakReg

- IDCTAB (F606W filter poly-coefficients + D2IMFILE)







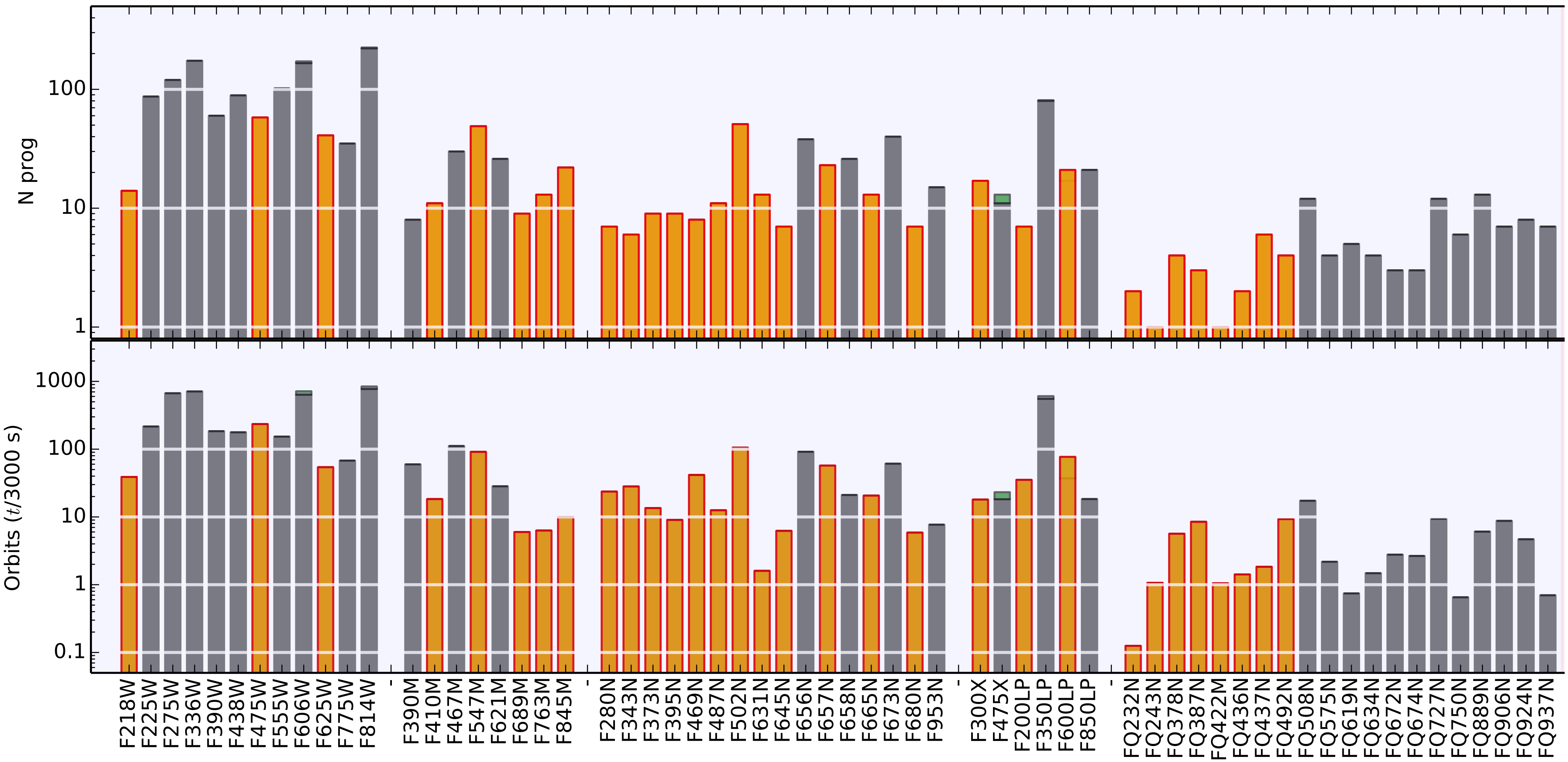
2D-residuals map after full geometric distortion – from left to right: F218W, F300X, FQ387N UVIS filters *w.r.t.* F606W

F218W, F300X, FQ387N - max-vector 0.2 – 0.5 pix × 500

- large patchy systematics
- problem with the gap between two CCD chips (plate-scale is not adequate for some filters)
- different direction of vector flows across overlapped area between F606W - F218W, F300X & FQ387N.

All these is indication of geometric scale problem (large systematic) or/and non-polynomial filter distortion

Filters that need distortion calibrations



Existing data from programs 11922, 11928, 12091, 12353, 12714, 13100, 13570

Astrometric Calibration of Broad, Medium, Narrow and Quad UVIS Filters

- **Requirements for full geometric distortion calibrations:**
  - Large residuals after the correction for filter-dependent correction are due to the insufficient number of observations (only 2 – 3 exposures per each filter, Kozhurina-Platais, WFC3-ISR-14-12).
  - 5 exposures per filter with ±40” Pos-Targs are necessary to firmly constrain the filter-dependent distortion

- **Number of UVIS Filters for astrometric calibrations:**

  Narrow filters – 10 of 16 need calibrations
  Medium Filters – 7 of 9 need calibration (F390M calibrated)
  Wide Band Filters – 2 filters (F218W, F625W)
  Extremely Wide – 2 filters (F300X, F475X)
  Quad filters – 3 filters (IDCTAB polynomial only)

- **Number of Orbits required to complete all UVIS filters**

  350 s $\times$ 5 $_{N\_exposures}$ = 1 orbit per filter $\times$ 6 $_{N\_Filters}$ = 6
  450 s $\times$ 5 $_{N\_exposures}$ = 1.2 orbits per filter $\times$ 15 $_{N\_Filters}$ = 18
  600 s $\times$ 5 $_{N\_exposures}$ = 2.0 orbits per filter $\times$ 3 $_{N\_Filters}$ = 6 orbits

Requires a total of <u>30 orbits</u> for all un-calibrated UVIS filters

Time Dependence of X-CTE and its Impact on Astrometry

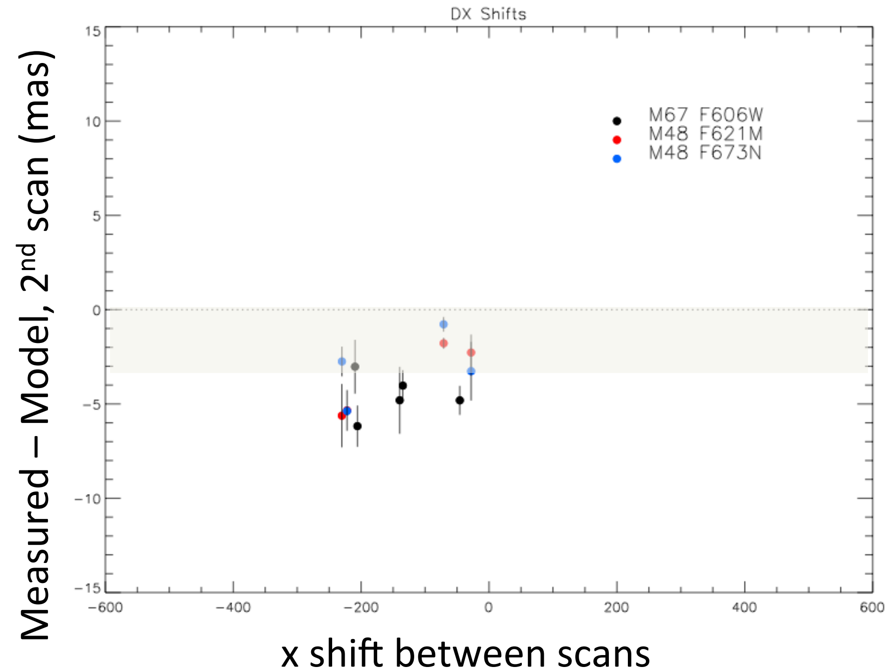
Number of External Orbits: 4

Number of Internal Orbits: 0

<u>Goals</u>: Improve the measurement of X-CTE and its effect on high-precision astrometry, and measure the time evolution over a 1 year baseline.

<u>Description of the observations</u>:
In program 13929 we observed M48 (in F621M and F673N) and M67 (in F606W), for 10 orbits dithering in the X-direction by a fair fraction of the field of view, to measure local variations in the accuracy of the geometric distortion solution. As a benefit, we paired the dithers where a bright line jumped across the x=2048 midline to measure the shift in astrometry due to X-CTE. The result from that X-CTE measurement is shown at right. We recorded the case when the jump was across the midline but still small, less than ~250 pixels to insure that the polynomial or scale correction we employ between dithers was not diluting or distorting the measurement of the X CTE effect.

We found a systematic difference of ~4 milipixels from the expected position (i.e., fit from the other dither). Because the X-CTE measurement was not the main focus of 13929, we did not get as many of these small line jumps as we could. Thus you see 13 such jumps in 50 exposures (10 orbits times 5 scans per orbit). In a repeat of 13929 we will insure topick dithers to get one jump in every pair of exposures, so with 4 orbits (20 exposures) we could get 10 points to add to this plot, also .



<u>This is an extension of program</u> 13929 (CY22), see also 13101

UVIS CCDs

To monitor the health of the UVIS channel we ask for 1059 internal orbits divided as follow:

1. 79 internal orbits (the cadence has been synchronized with the other HST instruments) to perform an anneal every month – Same as last cycle
2. 130 internal orbits to mitigate the hysteresis (bowtie) effect via a series of unsaturated and saturated internal flats. – Same as last cycle
3. 637 internals to perform a daily monitoring of the CCDs behavior using a series of dark and biases. Provide updated darks and hot pixel maps - Same as last cycle
4. 135 internals to assess how well post-flash is mitigating CTE with time using a series of unflashed darks - Reduced from last cycle
5. 60 internal orbits to monitor the stability of the post-flash LED with time. - Increased from last cycle
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. -- Same as last cycle

WFC3/UVIS Anneal

Same as CY22

Number of External Orbits: 0

Number of Internal Orbits: 79

Goals: Perform regular anneal procedures to 1) repair hot pixels and 2) acquire internal exposures to assess the anneal's effectiveness as well as produce reference files for the calibration pipeline.

Description of the Observations: WFC3 anneals are performed every 28 days, a cadence which interleaves the WFC3 procedure with those from other instruments, one instrument per 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 hysteresis-neutralizing image as well as verify that any hysteresis present has been successfully quenched. The Cycle 22 WFC3 anneals have been performed keeping the IR detector cold (IRTEMP=COLD). In Cycle 23, one iteration may 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: 79 total = 13 * 6 + 1

- 13 iterations provide seamless continuity across cycle boundaries.
- 6 orbits per iteration (2 before and 2 after each anneal for biases/darks + 1 orbit for the anneal itself + 1 orbit for the attached post-anneal bowtie visit)
- 1 orbit for one IR dark to be taken in the event an original anneal procedure (warming the IR detector) is performed during Cycle 23

This is a continuation of programs 12343, 12687, 13071, 13554, 14000.

UVIS Bowtie Monitor

Same as Cy22

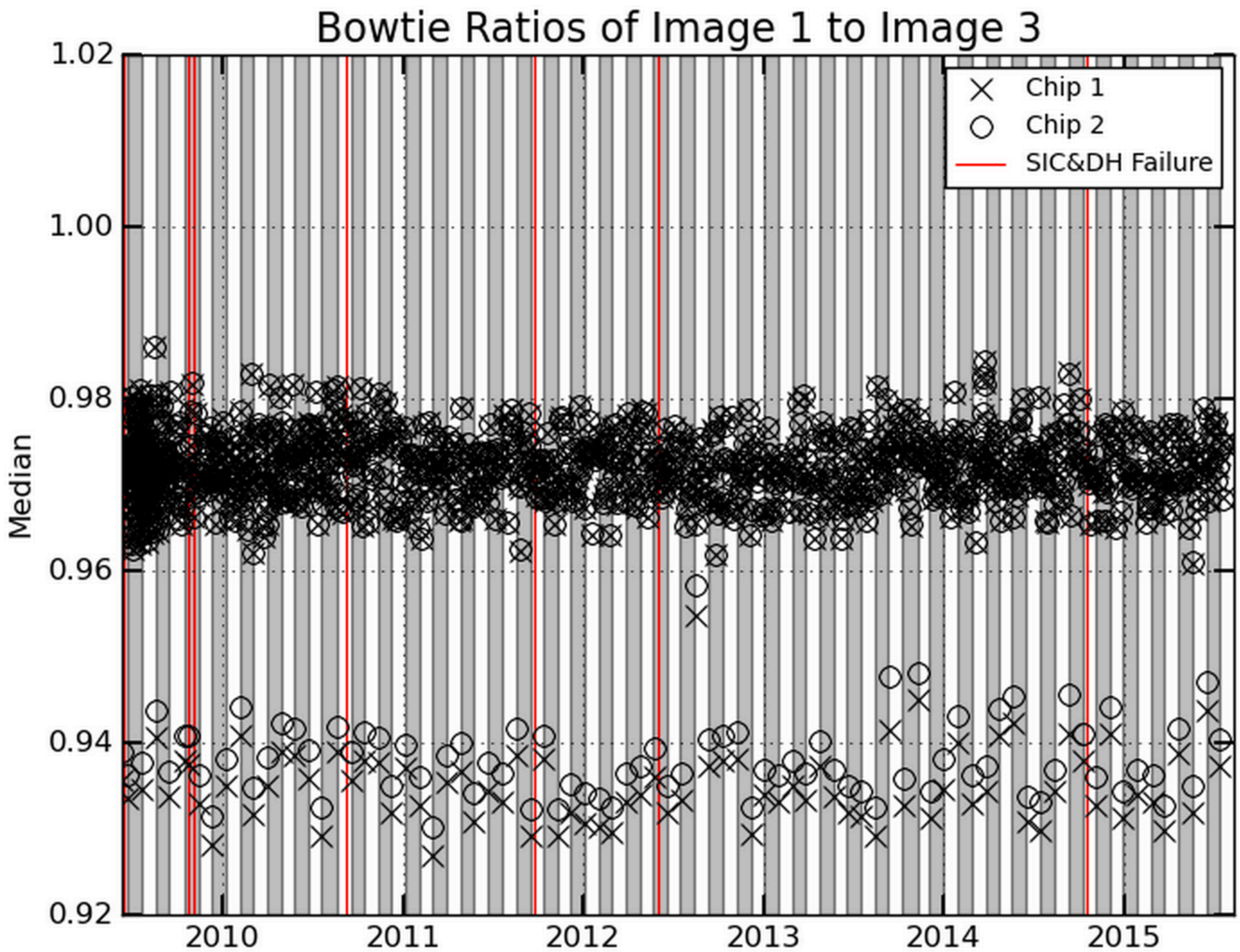
Number of External Orbits: 0

Number of Internal Orbits: 130

Goals: During thermal vacuum testing of internal flatfields, it was discovered that the UVIS detector exhibits occasional low-level (~1%) quantum efficiency offsets (i.e. hysteresis) across both chips, an effect later dubbed 'bowtie' due to its unique shape in the image ratios. The ground tests also revealed that the hysteresis could be negated by overexposing the detector by several times the full well amount. Thus, a multi-cycle 'bowtie monitoring' program was developed to detect and mitigate UVIS hysteresis on orbit. Like the preceding programs, each visit of this program acquires a set of three 3X3 binned internal flatfields. The first image is unsaturated in order to identify hysteresis, the second image is saturated to neutralize any QE offsets, and the third image is unsaturated to estimate the hysteresis removal efficiency.

Description of the Observations: Three UVIS internal tungsten flat field images are obtained using the F475X filter. This filter is utilized for (1) its high throughput, (2) its bandpass (<700nm), which is known to mitigate hysteresis and (3) its status as a low-priority filter for science observations. The three images are assembled into a single visit that is to be executed every three days: (1) an unsaturated image used as a check for hysteresis features, (2) a saturated 'QE pinning' exposure that is used to fill traps and mitigate QE offsets, and (3) an additional unsaturated image used to assess the hysteresis removal efficiency. Data analysis will include inspecting unsaturated frames and image ratios, identifying trends in image ratios over time, quantifying the efficiency of the neutralizing exposure, and investigating anomalies. The number of orbits includes room for contingency visits in the event of unexpected safing.

<u>This is a continuation of programs</u> 12344, 12688, 13072, 13555, 14001.


Bowtie Ratios of Image 1 to Image 3
Chip 1
Chip 2
SIC&DH Failure
Median
1.02
1.00
0.98
0.96
0.94
0.92
2010
2011
2012
2013
2014
2015

WFC3/UVIS CCD Daily Monitor

Same as CY22

Number of External Orbits: 0 **Number of Internal Orbits:** 637

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

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

Day 1 – 2 visits; one with 2 biases + 1 dark, one with 2 darks
Day 2 – 2 visits, each with 2 darks
Day 3 – 1 visit with 2 darks
Day 4 – 2 visits, each with 2 darks

All non-Day-1-Visit-1 darks use “no-move” darks (i.e. TARGNAME=DARK-NM) in which the CSM is not moved to the IR position and a narrow-band filter configuration is employed to reduce any scattered light. Since Day-1-Visit-1 Visits start with biases, and thus the CSM is in the IR position, these darks do not have to be “no-move" nor does a narrow filter have to be employed. Several different filters are used in order to distribute usage across multiple wheels thereby avoiding overuse of any particular wheel.

Orbits needed: **637 (internal)**

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

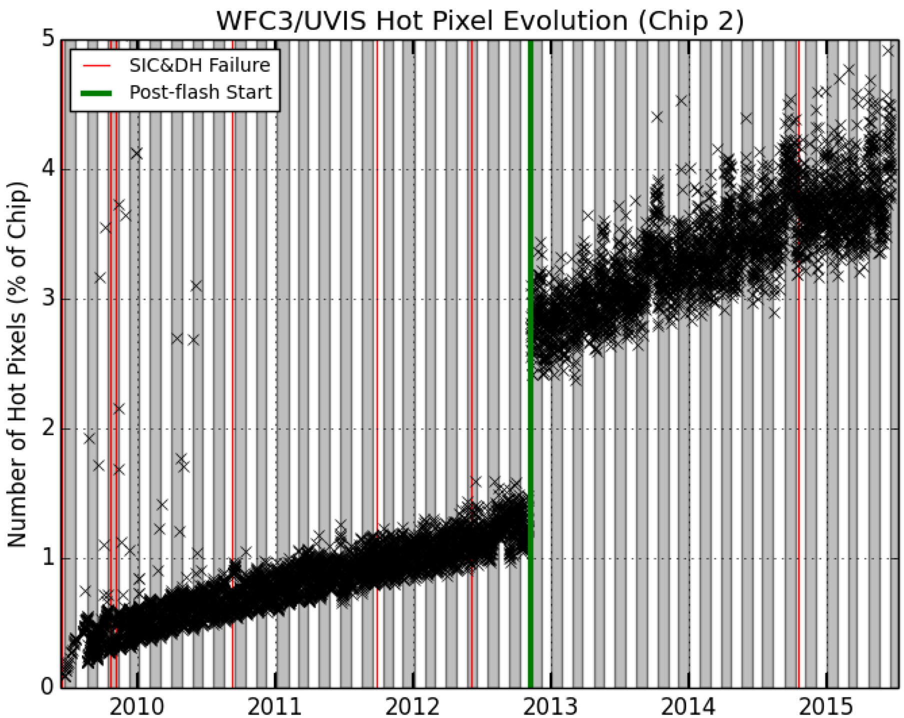
<u>This is a continuation of programs</u> 12342, 12689, 13073, 13556, 14002, 14003, and 14004.

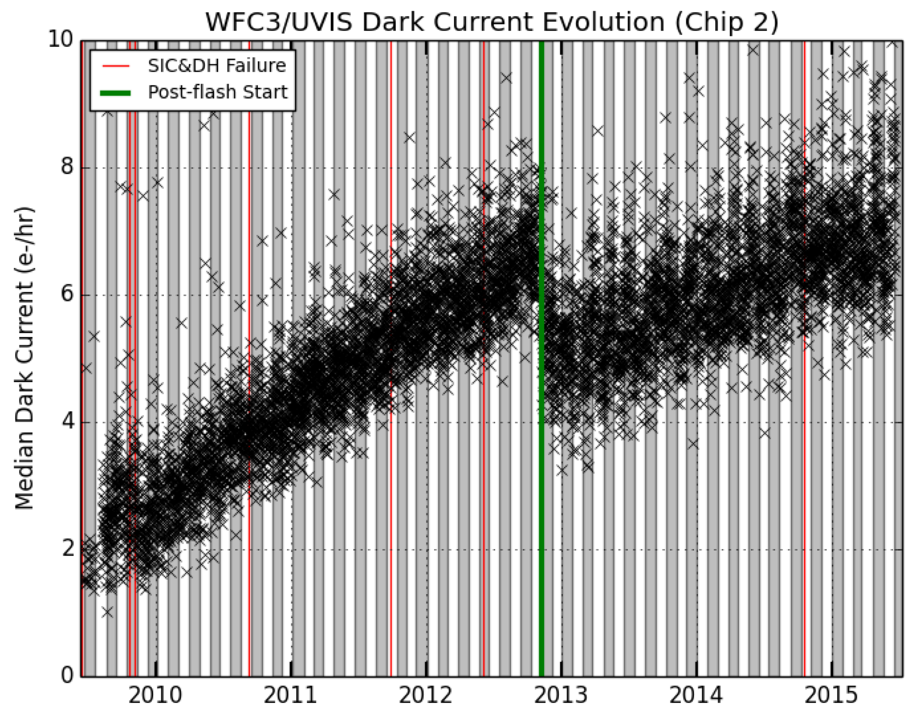
WFC3/UVIS CCD Daily Monitor

Same as CY22

Number of External Orbits: 0 **Number of Internal Orbits:** 637

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





The hot pixel evolution (left) and the median dark current evolution (right) of WFC3/UVIS chip 2 since the installation of WFC3 on HST. Each gray/white region represents anneal cycles. Note that the implementation of post-flash occurred on day 1246.

UVIS Un-flashed Monitor

Same as CY22

Number of External Orbits: 0

Number of Internal Orbits: 135

Goals: Temporal changes in CTE losses and the efficacy of the post-flash mode are monitored by a series of non-postflashed WFC3/UVIS darks taken before and after the monthly WFC3/UVIS anneal procedures. A large number of internals are taken as part of a daily monitor of warm/hot pixel growth and read noise, however they are all post-flashed. Thus, a small number of un-flashed internals are required to monitor the changes in CTE losses over time. These un-flashed internals, in conjunction with the post-flashed internals, will allow for an assessment of how well the post-flash is mitigating the CTE losses.

Description of the Observations: 900s darks in each iteration, 1 dark per visit, 5 visits pre and post-anneal. 13 anneals in cycle 23 times 10 orbits each, plus extra orbits to bridge end of cycle 22 last anneal

<u>This is a continuation of programs</u> 13559, 14005

WFC3/UVIS Post-flash Monitor

Same as CY22

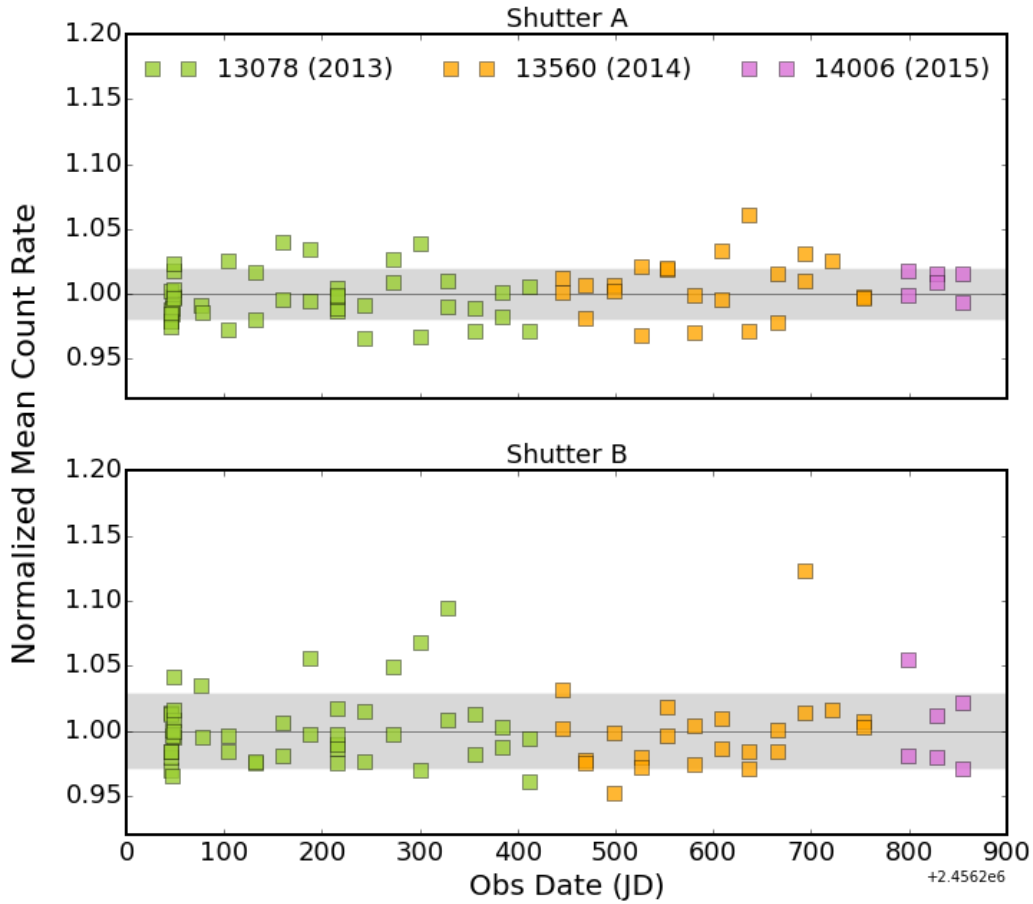
Number of external orbits: 0 **Number of internal orbits: 60**

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 (<12 e^-) data are now making use of the post-flash (PF) mode in WFC3/UVIS. In this cycle, we propose monthly monitoring of the lamp characteristics plus sufficient orbits to allow a new generation of post-flash CRDS 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×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= 12x3 (pattern+ brightness check)+12(new reference)+12(on-hold)

This is a continuation of programs 13078, 13560, 14006



The figure above shows the Normalized Mean Count Rate from 2013 to 2015 of the UVIS2-C1K1C subarray with flash = 12 e^-. The +/- standard deviation of the entire data is shown with the grey bar centered at a mean count rate of 1.00.

Most values lie within the 1-sigma bar, the few outliers are being investigated for scattered light contamination.

UVIS Gain Stability

Same as CY22

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.

This is a continuation of programs 11906, 12346, 12690, 13168, 13561, and 14007

IR Detector

To monitor the health of the IR channel we ask for 121 internal orbits:

1. 95 internal orbits to obtain IR dark calibration files. The number of orbits is dictated by the observing modes requested by GOs. - Same as last cycle
2. 10 internal orbits (saturated internal flats) to monitor the IR non-linearity and update the calibration reference file. - Same as last cycle
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. - Same as last cycle

IR Dark Monitor

Same as CY22

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

Goals: This program obtains data required to support the IR dark calibration. The structure overall is very similar to the previous IR dark monitor programs. About a quarter of the orbits are used for regular collection of SPARS200/full-frame dark observations. These long observations are used to monitor trends in the bad pixels (hot, unstable, or dead), zeroth read level, and dark current. The remaining portion of the orbits will be used to collect dark ramps for generating stacked IR dark calibration files for use by the MAST pipeline. The ramps will be collected for each observing mode at a cadence roughly scaled with the popularity of each observing mode in approved Cycle 23 programs, with the exception of the newly implemented SPARS5 sample sequence, which will be allocated extra orbits for this cycle only.

Description of the Observations: Full-frame and subarray dark calibration images will be collected. The total number of images collected over the course of the cycle for a given mode is based on the total number of input ramps used in the current superdark for that mode, and the popularity of that mode in cycle 22 external science observations. The IR dark current has remained effectively unchanged since launch (Hilbert & Petro, WFC3 ISR 2012-11). This stability allowed us to greatly relax the scheduling constraints compared to WFC3/IR dark monitor programs from previous cycles. With the exception of the SPARS200/Full-Frame hot-pixel monitoring observations (which occur once within every 2-week period), all observations have no set scheduling parameters, other than that they have to be taken sometime during Cycle 23.

<u>This is a continuation of programs</u> 12349, 12695, 13077, 13562, 14008

WFC3/IR Linearity Monitor

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

Goals: Monitor the signal non-linearity of the IR channel and, when necessary, update the IR channel non-linearity calibration reference file.

Description of the Observations: Each internal orbit will be used to acquire one internal flat (intflat) exposure up to saturation level in order to provide a pixel-to-pixel map of the non-linearity of the detector. Minimizing persistence is critical for this program in order to avoid erroneous linearity results. In past cycles, persistence effects were mitigated by preceding and following each intflat with a dark current exposure. However, starting in Cycle 22, we removed the following darks and designate each visit as a 'worst actor'; this saves 10 CSM moves. In practice, the analysis of the linearity in the end did not make use of the actual data in the preceding darks although they were helpful for assessing whether persistence was an issue. We note that due to an oversight in Cycle 22, we applied for 9 internal orbits instead of 10 as all previous cycles had. We hope to go back to 10 this cycle for consistency.

This is a continuation of programs 12352, 12696, 13079, 13563, 14009

WFC3/IR Gain Monitor Same as CY22

Number of external orbits: 0

Number of internal orbits: 16

<u>Goals</u>: Measure the gain of the IR channel and monitor the health of the instrument by comparing to values from previous cycles.

<u>Description of the Observations</u>: This proposal is unchanged from last cycle's. Each orbit of the 16 identical orbits will be used to acquire an internal flat ("intflat") to compute 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 a short low S/N narrowband exposure, to ensure the internal lamp is at full output. The gain intflats are acquired at ~1/2 full-well to minimize non-linearity corrections. Each dark current exposure will be collected following the 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.

<u>This is a continuation of programs</u> 12350, 12697, 13080, 13564, 14010

CTE Characterization and Calibration

This part of the calibration program requires 8 external and 48 internal orbits.
As in Cycles 20–22, GOs can mitigate CTI effects using post-flash. To support these efforts we ask:

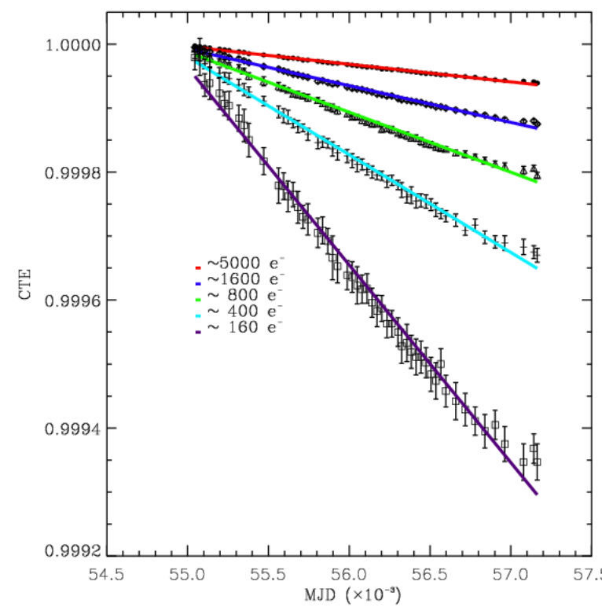
1. 12 internal orbits to measure and monitor CTE via Extended Pixel Edge Response (EPER). Frequency every other month. – Same as last cycle
2. 8 external orbits to observe stellar fields characterized by different crowding and background (2 fields in 47 Tuc and one in NGC 6791) to calibrate the photometric and astrometric CTI corrections. – Increased from CY22
3. 36 internal orbits with charge-injected bias to monitor the length of the CTE trails. This information will be used as an input for J. Anderson's CTE algorithm. – Same as last cycle

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 (2 every other month) 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 flat fields 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 from Aug 2009 through Aug 2015 as a function of time for a range of signal levels. CTE continues to decline, decreasing most rapidly for the lowest signal level (160 e-). The apparent leveling off of CTE losses in recent data is under investigation.

__This is a continuation of programs__ 11924, 12347, 12691, 13082, 13565, 14011

WFC3/UVIS External CTE Monitor: Star Clusters

Number of external orbits: 8 **Number of internal orbits: 0**

Goals: Monitor CTE degradation as a function of epoch and source/observation parameters. Calibrate photometric corrections. Provide data to test and monitor the Anderson pixel-based CTE correction model for WFC3/UVIS.

Description of the Observations: We continue, as begun in Cycle 20, using post-flash to sample background levels and monitor the efficacy of the post-flash model for CTE mitigation. Exposures of NGC 6791 and 47 Tuc in F502N (this filter gives approximately zero background) will monitor the maximum CTE in different field densities, and long exposures, dithered by 2000 pixels in detector Y, will measure absolute CTE. There will be a few short exposures of the sparse cluster NGC 6791 as fillers at ends of orbits for long-short flux ratio tests.
Starting this cycle, we propose adding two orbits to the six observed last cycle. We require short 30-second exposures of 47 Tuc, both with and without post-flash 12 e-. The purpose is to perform short-long comparisons of a *dense* field (in contrast to short-longs of *sparse* NGC 6791) and to perform an additional test on the pixel-based CTE correction scheduled to be incorporated into the WFC3 calibration pipeline this fall. We will also take long exposures at post-flash level 20 e-. This will test how effectively a higher post-flash level mitigates CTE loss, since it may become necessary in the future, as CTE continues to degrade, to advise GOs to apply higher post-flash levels.
In summary, there will be one orbit for NGC 6791 and three for 47 Tuc (observed in five different non-zero background levels). Four orbits per epoch, times two epochs, to yield eight orbits total.

This is a continuation of programs 12379, 12692, 13083, 13566, 14012

Same as CY22

Characterization of UVIS traps with Charge-Injection

Number of external orbits: 0

Number of internal orbits: 36

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

Description of the observations: We request 36 internal orbits to monitor the growth of UVIS traps. Line 25 charge-injected biases will be acquired every 10 days. Observations are designed to give the schedulers large flexibility, and therefore minimize the impact on the number of CSM moves.

<u>This is a continuation of programs</u> 12348, 12693, 13084, 13569, 14013

WFC3 Photometric performance

31 external orbits and 1 internal orbit will be used to:

1. 15 orbits will be used to measure the photometric throughput of WFC3 in a series of key filters every 5 weeks to validate instrument throughput stability (11 orbits) and characterize the wavelength dependency of the throughput decrease observed at optical wavelengths (4 orbits). Decreased from last cycle
2. 3 external + 1 internal orbits will be used to monitor the accuracy of the shutter mechanism after 6 years of operations. – Same as last cycle
3. 12 external orbits are requested to check photometric zero-points for a subset of the WFC3 UVIS and IR filters. Decreased from last cycle
4. 1 external orbit is requested to cross-calibrate WFC3/IR – NICMOS count rate dependent non-linearity at blue wavelengths. - New program!

WFC3/UVIS Contamination Monitor

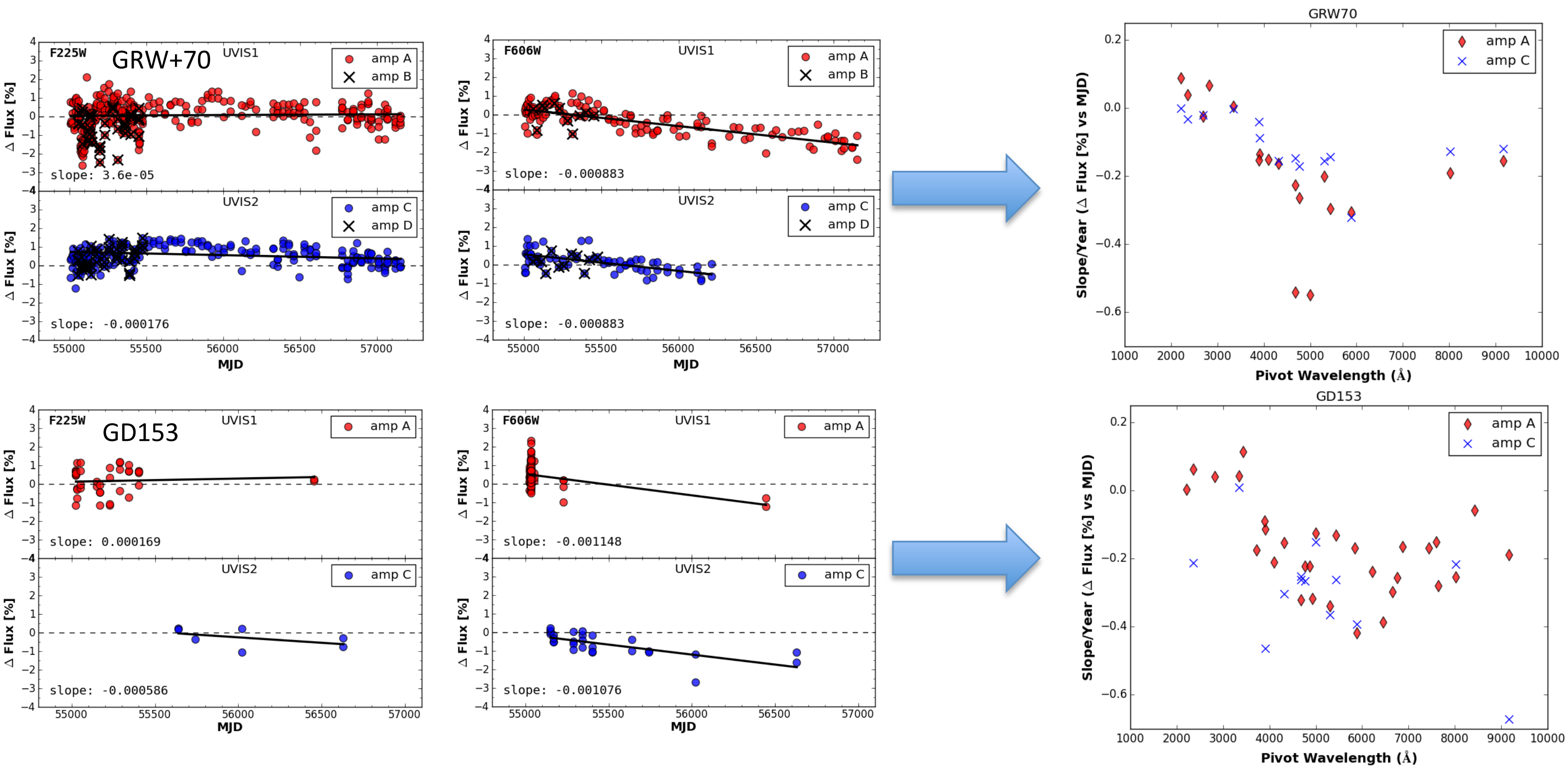
Number of External Orbits: 15 **Number of Internal Orbits:** 0

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. While no contamination effects have been detected with prior data, small long-term photometric drifts are present in some filters (Gosmeyer et al., ISR 2014-20). These drifts do not appear to be due to changes in shutter behavior (Sahu et al., ISR 2015-12).

Description of the Observations: The monitor observing cadence is deliberately out of synchronization with the monthly anneals in order to sample the phase space. Each iteration obtains dithered subarray observations of a standard star in a subsample of filters in the UVIS, including the UV grism, on both UVIS detectors.
Given recent results that the white dwarf spectrophotometric standard GRW+70d5824 may not be as stable as previously thought (Bohlin & Landolt 2015), we propose this cycle to begin using another white dwarf standard (GD153), interleaving it with a small number of GRW+70 observations to tie it into the past monitor data.

15 orbits total to cover the observing cycle and provide GD153/GRW overlap
  11 orbits GD153 (one orbit every 5 weeks)
  4 orbits GRW (two early in cycle, one mid- and one late-cycle)

<u>**This is a continuation of programs**</u> 12333, 12698, 13088, 13574, 14018.



- GRW+70d5824 has been a long-time HST photometric standard (e.g. Turnshek et al., 1990; Bohlin et al., 1990).
- However: Bohlin & Landolt (2015) report a slight decline in brightness for GRW+70: 5-6 mmag/yr in U,B at 3 σ significance, ~3 mmag/yr in V,R,I at 2 σ significance.
- While these results do not correspond to what is seen in the on-orbit WFC3 data, it casts sufficient doubt on GRW+70 as a standard to merit switching targets.
- Of the standards available with some archival WFC3 data, GD153 is the best candidate in terms of target brightness and wavelength/epoch coverage.

UVIS Shutter Characterization

Number of external orbits: 3

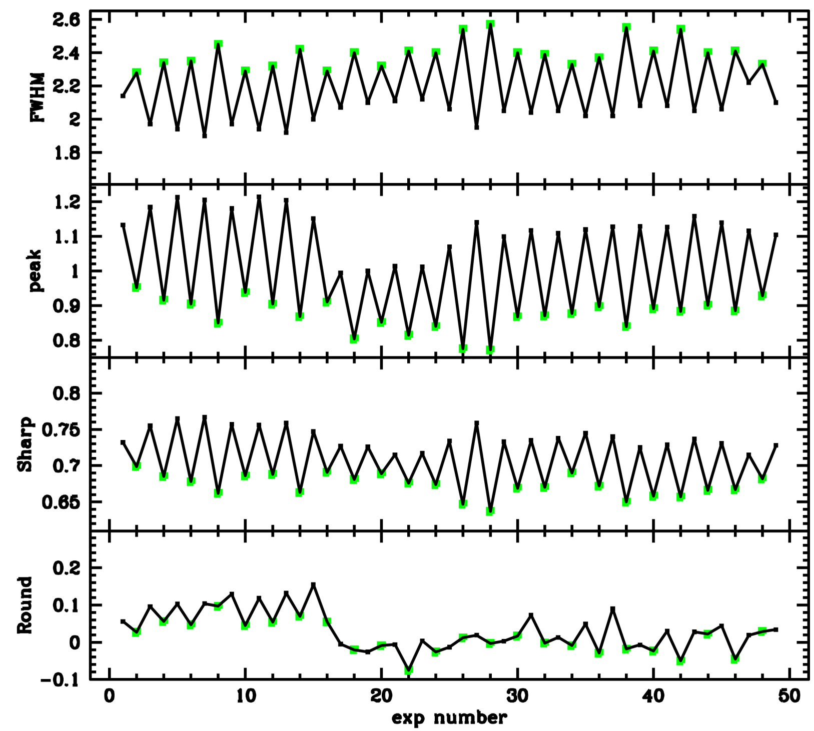
Number of internal orbits: 1

<u>Goals</u>: The goal is to characterize the performance of the shutter blades. The three specific objectives are:

(i) to check the accuracy and stability of the blades by repeating the SMOV test done 5 years ago,

(ii) to check the photometric behavior of both the shutter blades, for short vs. long exposures, and

(iii) to check for any shading effects by the shutter.



UVIS Shutter Characterization

Number of external orbits: 3 **Number of internal orbits: 1**

Description of the Observations: (i) We will repeat SMOV and Cy22 tests to characterize the shutter and look for any deviations (2 external orbits). We will include a brighter target than was observed in Cy22 to improve the statistics for the short exposures.

(ii) We will characterize the photometric behavior of the shutter blades A and B separately. In particular, the shortest exposures are known to be anomalous, but its possible dependence on the blade is currently unknown. Now that we are offering BLADE=A option for observations with better PSF, it is important to characterize the photometric behavior separately for the two blades (1 external orbit).

(iii) Internal flat fields will be used to quantify any shutter shading effects in the UVIS channel (1 internal orbit).

This is a continuation of programs 11427 (SMOV), 14019

Cycle 23 WFC3 UVIS and IR Photometry

Number of external orbits: 12

Number of internal orbits: 0

Goals: Monitor the photometric throughput and stability, measure zeropoints and determine color term corrections for **WFC3 UVIS and IR filters** as a function of time, wavelength and source brightness. Previous programs indicate that UVIS sensitivity is time dependent, hence zeropoints are also time dependent**. This is a continuation of CY 17–22 programs**.

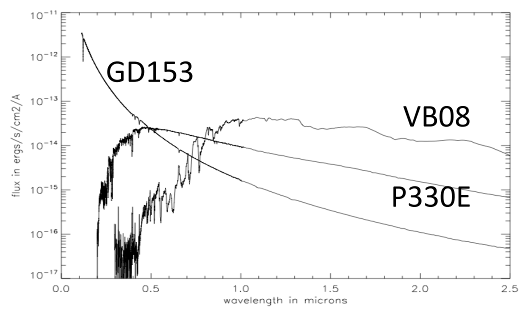
Description of the observations:

WFC3 UVIS: We image G191B2B, GD153, GD71 and P330E in a subset of broad- and medium-band UV and VIS filters at the corners (4 amps), using postflash. In Cycles 20 and 21 we obtained observations in ALL UVIS filters at all 4 corner subarrays. 2 orbits per star = 8 external orbits

Star/Cycle	SMOV+17	18	19	20	21	22	23
G191B2B	AC, ALL					ABCD, subset	ABCD, subset
GD153	ABC, subset	A, subset		AD, ALL	BC, ALL	ABCD, subset	ABCD, subset
GD71	AC , subset	C , subset	C, subset			ABCD, subset	ABCD, subset
P330E	A, subset	A, subset		AD, ALL	BC, ALL	ABCD, subset	ABCD, subset

WFC3 IR: GD153, GD 71 P330E are imaged in all IR filters. 1 orbit per star = 3 external orbits

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



WFC3 Grism Spectroscopy

11 external orbits will be used to:

1) 4 orbits are requested to improve the flux calibration for both the IR grisms
   Same as last cycle
2) We ask 4 orbits to improve the wavelength calibration for both the IR grisms
   Same as last cycle
3) We request 1 orbit to monitor the UVIS grism wavelength stability in both chips
   Cut in half from last cycle
4) 2 external orbits are needed to monitor the UVIS grism flux in both chips.
   New program!

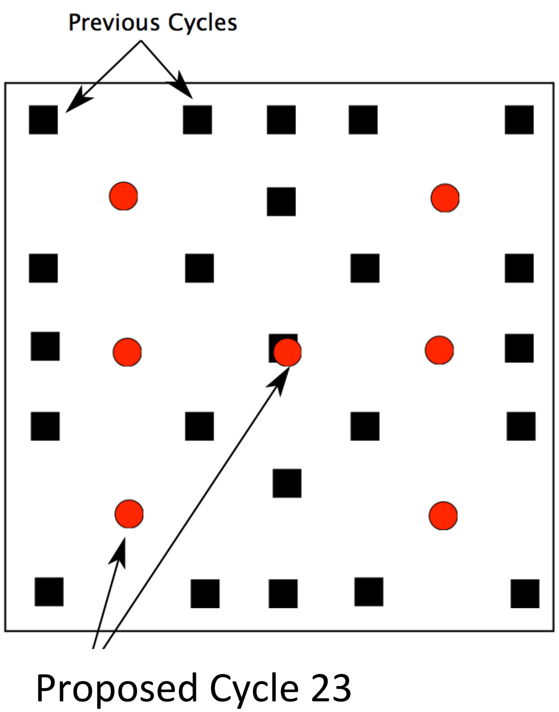
WFC3 IR grisms wavelength calibration stability and calibration

Number of external orbits: 4 (2 per grism)

Number of internal orbits: 0

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

Description of the observations: 7 pointings of VY-22 using the G102 and G141 grisms. 1 previously observed position (center), and add 6 new positions to better calibrate the 2D variability of the grism wavelength dispersion relations.



<u>This is a continuation of programs</u> 12356, 12703, 13093, 13580, 14023.

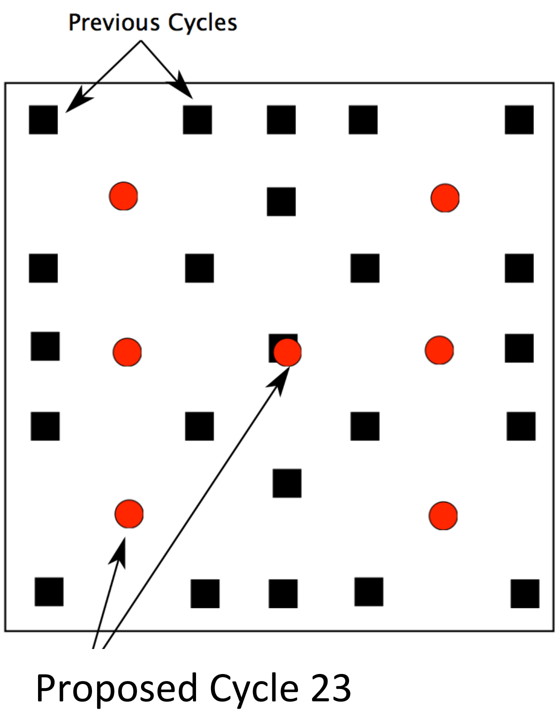
WFC3 IR grisms flux/trace calibration stability and calibration

Number of external orbits: 4 (2 per grism)

Number of internal orbits: 0

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

Description of the observations: 7 pointings of GD-153 using the G102 and G141 grisms. 1 previously observed position (center) and add 6 new positions, improving the 2D sampling of the field-of-view to better calibrate the 2D variability of the grism wavelength dispersion relations.



<u>This is a continuation of programs</u> 12357, 12702, 13092, 13579, 14024.

WFC3 UVIS grism wavelength calibration stability and calibration

Number of external orbits: 1

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: 4 pointings (2 per CHIP) of WR-14 using the G280 grism. Two (2) positions on each CHIP will repeat (critical as they show +1 and -1 orders) previously observed position and verify the stability of this mode.

<u>This is a continuation of programs</u> 12359, 12705, 13091, 13578, 14025.

WFC3/IR Flux Calibration of the G102 & G141 -1st orders

Number of external orbits: 2

Number of internal orbits: 0

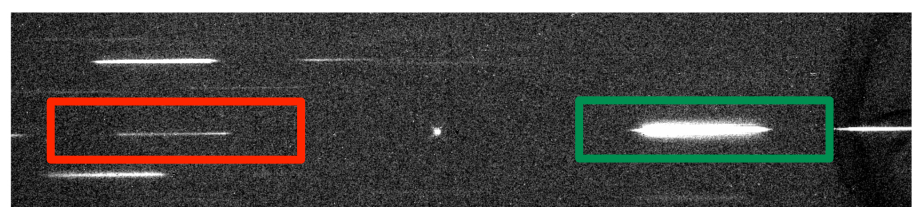
Goals: Improve the flux calibration and correct and map the sensitivity curve of the -1st orders of G102 and G141 to enable accurate and precise spectroscopic observations of bright targets. Continuation of SMOV, Cy 17 & 20 programs.

<u>Description of the observations</u>: One external orbit for each of the two IR grisms will be used to obtain S/N~100 -1st order spectra of the brightest photometric standard star, G191B2B, placed at 5 positions on the detector.

Observations of P330E in the G141 -1st order show that the sensitivity curve is incorrect, therefore high S/N spectra of the WD standard are needed to correct the shape, consistent with measurements for the +1st orders.

S/N of the -1st order spectra from existing calibration exposures is not useful as the exposure times were optimized for the much brighter primary +1st order (see figure). Because the -1st orders are ~ 100 times less sensitive than the +1st orders, obtaining high SNR spectra in the -1st order saturates the +1st order.

1 orbit per grism = 2 external orbits



G141 image of GD153. brightest pixel above sky
−1st order 1 e-/s / +1st order: 90 e-/s (sky = 2.2 e-/s)

Flatfield Calibrations

We request 282 internal orbits to:

1) Monitor a population of UVIS pixels with anomalous QE, 51 internal orbits
   Same as last cycle

2) Monitor the health of the UVIS filters via int-flats, 13 internal orbits; Same as last cycle

3) Monitor the health of the IR filters via int-flats, 18 internal orbits; Same as last cycle

4) Monitor the health of the CSM by observing the bright earth, 200 internal orbits;
   Same as last cycle

Same as CY22

WFC3/UVIS Internal Flats

Number of external orbits: 0

Number of internal orbits: 13

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

<u>Description of the Observations</u>: We will acquire internal flats in all UVIS filters once early in the cycle. This consists of 3 orbits with the D2 lamp for the filters F218W, F200LP, F225W, F275W, F280N, F300X, F336W, F343N, F373N, F390M, F390W, F395N, FQ232N, FQ243N, FQ378N, and FQ387N. Eight orbits with the Tungsten lamp will 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

<u>This is a continuation of programs</u> 11432, 11914, 12337, 12711, 13097, 13586, 14028

Same as CY22

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 near the end). This requires another 6 orbits (2x3) for a total of 18 internal orbits

This is a continuation of programs 11433, 11915, 12338, 12712, 13098, 13587, 14029

Same as CY22

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

Number of external orbits: 0 **Number of internal orbits: 51**

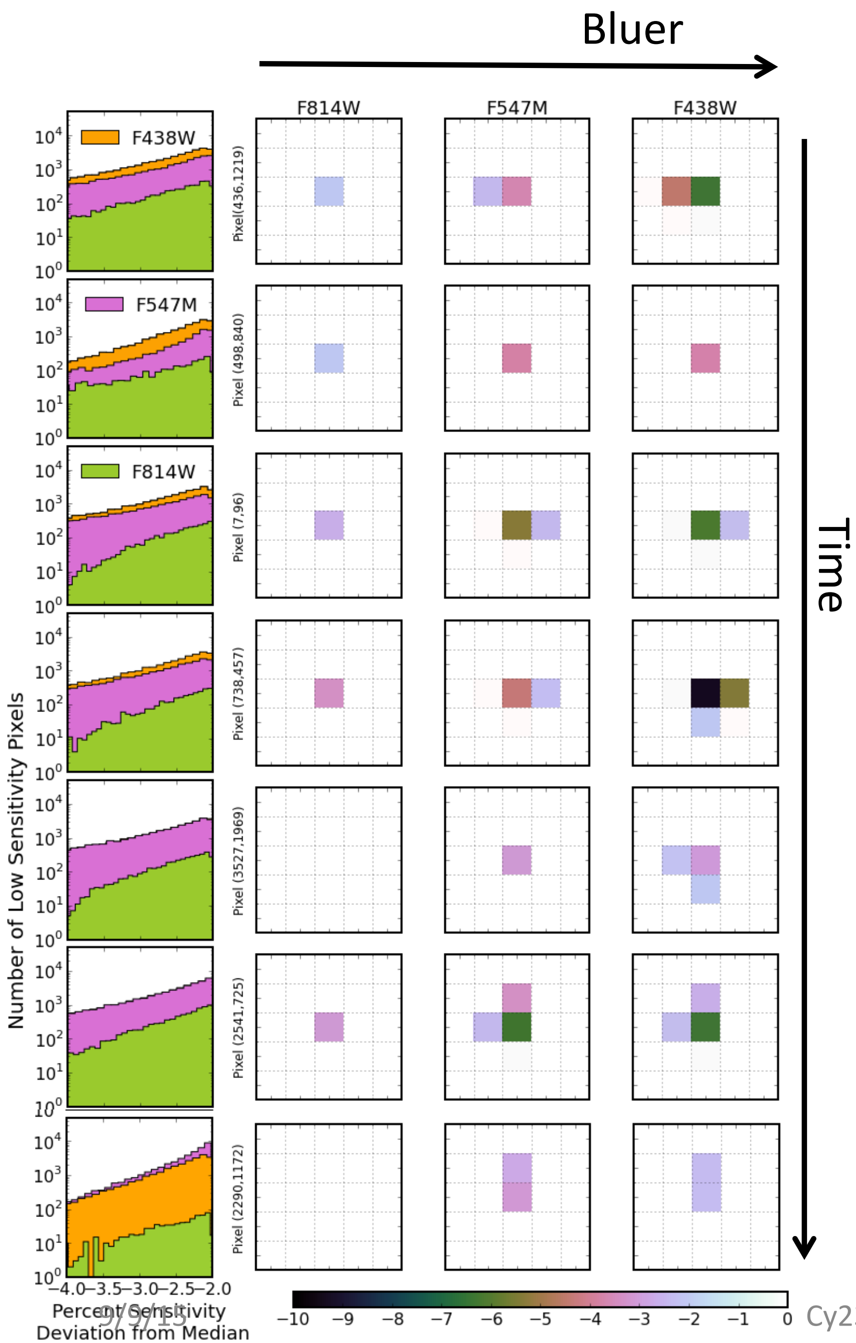
Goals: This program continues to monitor the population of pixels exhibiting anomalous QE variations between anneals. These pixels are randomly distributed across the detector and develop lowered sensitivity during the time between anneals. The sensitivity loss is greater in the blue than in the red and the population that develops is seemingly unique per each cycle. This program will focus on constraining the maximum low-sensitivity population existing before an anneal in both the UV and Visible filters.

Description of the Observations: Analysis of data from previous proposals has indicated that the low-sensitivity population in the UV tends to have a grouping (of a few pixels) behavior. To better sample the UV this cycle, we will acquire 6 long orbits using the D2 lamp (to minimize lamp cycles), 1 orbit every other month in the week before the anneal – capturing the maximum number of pixels with lowered sensitivity.

For the visible filters, we will obtain 36 orbits, 3 per month, using the tungsten lamp, to obtain data the week before the anneal, where the population is largest. Nine more orbits will be acquired, 3 early cycle, 3 during the middle, and 3 near the end, to sample the population numbers immediately following an anneal, where the population is lowest. The extra orbit each month will allow additional wavelength coverage between F814W and F438W, to better sample how the population grows towards bluer wavelengths

All UV orbits will require non-int to minimize cycling of the D2 lamp.

This is a continuation of programs 13169, 13585, 14027.



The column on the left shows the total number of pixels with lowered sensitivity as a function of the percent of sensitivity deviation from a median 'true' internal flat. The total population grows with bluer wavelengths.

The F814W, F547M, and F438W columns show pixel regions (central pixel denoted to the left of the F814W image figures). On average, a pixel with lowered sensitivity in F814W sees an increased sensitivity deficit with bluer wavelengths. The affected pixel can grow into a small group of pixels experiencing lowered sensitivity with bluer wavelengths.

Each row is a separate epoch of data.

Same as CY22

CSM Monitor

Number of external orbits: 0

Number of internal orbits: 200

<u>Goals</u>: This program will monitor, as often as practical, the position of the CSM. It is hoped that by doing so, we may detect anomalies before the CSM fails entirely, allowing us to postpone the latter.

<u>Description of the Observations</u>: Observe the dark Earth in F153M exactly as we have been doing for years.

<u>This is a continuation of programs</u> 13588, 14030.