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**Instrument Science Report WFC3 2015-07**

# WFC3 Cycle 22 Calibration Program

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May 11, 2015

**ABSTRACT**

*The Cycle 22 WFC3 Calibration Program runs from November 2014 through October 2015 and is designed to measure and monitor the behavior of both the UVIS and IR channels. The program was prepared with the planned usage of WFC3 in mind, to provide the best calibration data and reference files for the approved scientific programs. During Cycle 22 the WFC3 team is using 113 external and 1620 internal orbits of HST time divided in 32 different programs, grouped in eight categories: UVIS Detectors, IR Detector, CTE Characterization and Calibration, Astrometric Calibrations, Characterization of IR Persistence, WFC3 Photometric Performances, WFC3 Grisms, Flatfields Calibrations.*

## Introduction

The Wide Field Camera 3 (WFC3) is the panchromatic (wavelength coverage ranging from 200 nm to 1700 nm) 4$^{th}$ generation instrument of the Hubble Space Telescope (HST), which was installed during the last HST servicing mission (SM4) in May 2009, replacing the Wide Field Planetary Camera 2 (WFPC2).

WFC3 has two independent channels:

- The UVIS channel is sensitive to the wavelength between 200 nm and 1mμ, uses two 4096×2051 pixel CCD detectors with a pixel scale of 0".0395 and a field of view (FoV) of 162"×162". It is equipped with one UV grism and 62 narrow-, medium-, and broadband filters, 42 of which cover the entire UVIS FoV, and the remaining 20 filters are organized in 5 sets of "quad".
- The IR channel operates between 800 nm and 1.7mμ. It consists of a 1024×1024

HgCdTe detector array, of which the central 1014×1014 pixels are used for imaging. The FoV is 136”×136” and the pixel scale is 0”.135×0”.121. The IR channel is equipped with 15 broad-, medium- and narrow-band full-frame filters, and two grisms.

A complete description of WFC3 can be found in the WFC3 Instrument Handbook (Dressel, L. 2014). Instructions on how to reduce WFC3 data can be found in the Data Handbook (Rajan et al. 2010).

| 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% | 113 | 1620 |

**Table 1:** WFC3 usage since the installation of NHC. The usage is expressed as percentage of HST total orbits. Since they have a different impact on the execution of GO programs, internal and external calibration orbits are accounted for separately. *Multi Cycle Treasury (MCTs) Programs, Snapshot (SNAPs) proposals and Frontier Fields (FFs) are not included in the estimate of the GO time. **Delta Calibration Programs are included in the estimate of the time assigned for calibration.

During every observing cycle, the WFC3 team runs a calibration program to measure and monitor the behavior of both WFC3’s channels. This ISR describes the WFC3 Calibration Program for Cycle 22 (CY22). Previous calibration programs have been described in Deustua et al. (2010), Deustua (2011), Sabbi et al. (2012, 2013, 2014). CY22 program runs from November 2014 through October 2015 and it is designed measure and monitor the behavior of both WFC3’s channel. The program’s main goal is to provide the best calibration data and reference files for the approved scientific observing programs.

The ISR is organized as follow. In Section 1 we discuss the usage of WFC3 with time, while Section 2 presents the calibration requirements. Sections 3 to 10 describe the eight CY22 calibration categories (UVIS Detectors, IR Detector, CTE Characterization and Calibration, Astrometric Calibrations, Characterization of IR Persistence, WFC3 Photometric Performances, WFC3 Grisms, Flatfields Calibrations), Section 11 provides some information on how to access the PhaseIIs for each calibration program, and where results from each program will be published.

## 1. Usage of WFC3 with time

| | 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% | 60% | 40% |

**Table 2:** WFC3 usage since the installation on HST from GOs. The usage is expressed as percentage of WFC3 number of exposures, and has been divided in UVIS vs. IR channels, imaging vs. spectroscopy. Multi Cycle Treasury (MCTs) Programs, Snapshot (SNAP) proposals and Frontier Fields are not included.

With almost 50% of the total number of HST orbits available for science (Table 1), in Cycle 22 (CY2) WFC3 continues to be the most widely requested HST instrument. Table 2 shows the usage of the available WFC3 observing modes (UVIS vs IR channel, imaging vs spectroscopy) in the past five cycles. With 40% of the exposures acquired using grisms, CY22 confirms the importance of the IR spectroscopic capabilities of WFC3 from the General Observers (GOs).

Both the WFC3 channels are very popular. Figures 1 and 2 show how the filter request is changed from CY18 to CY21 for the UVIS and the IR channels respectively. Figures 3 and 4 highlight WFC3 filter usage for the only CY22.

The IR filter F160W is the most used filter in CY22, and with more than 1,000,000 seconds, alone it accounts 1/6 of the total WFC3 exposure time. The second most requested filter is F105W (still on the IR channel) followed by the IR grism G141 (510,000 seconds).

WFC3 is being used in many different ways for different scientific purposes. Some characteristics of the CY22 scientific program are as follows:

- GOs are using for the first time since WFC3's installation on Hubble, all the 15 IR filters in a single cycle;
- They have requested 46 out of the available 52 UVIS filters, with 30% of these exposures being collected in the near UV;
- ~30% of all the WFC3 exposures will involve spatial scan;
- In 67% of the UVIS exposures GO are using post-flash to mitigate the degradation in charge transfer efficiency.

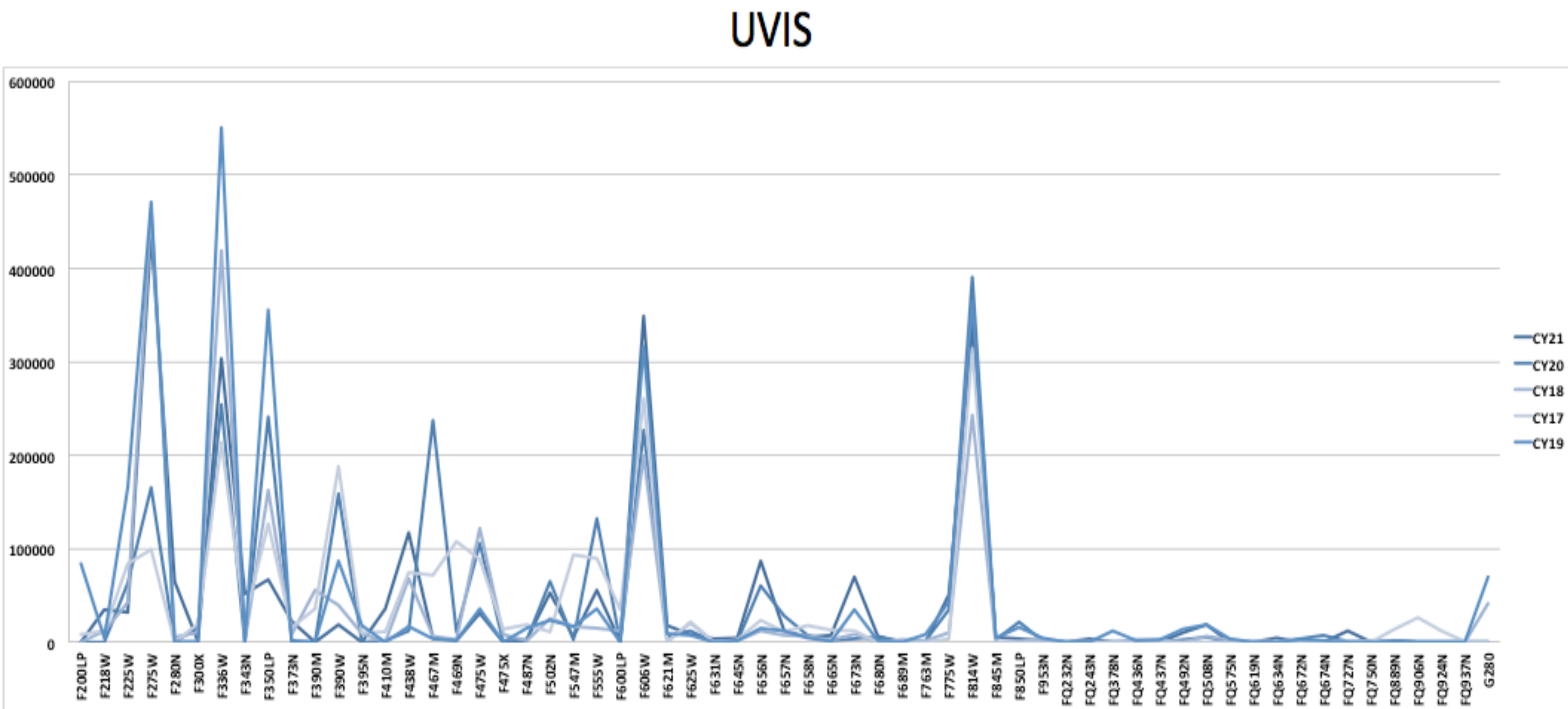


**Fig. 1:** GOs filter usage from Cycle 17 to 21 for all the filters available on the UVIS channel Data are measured in number of seconds, filters are ordered from the shorter to the longer wavelengths.

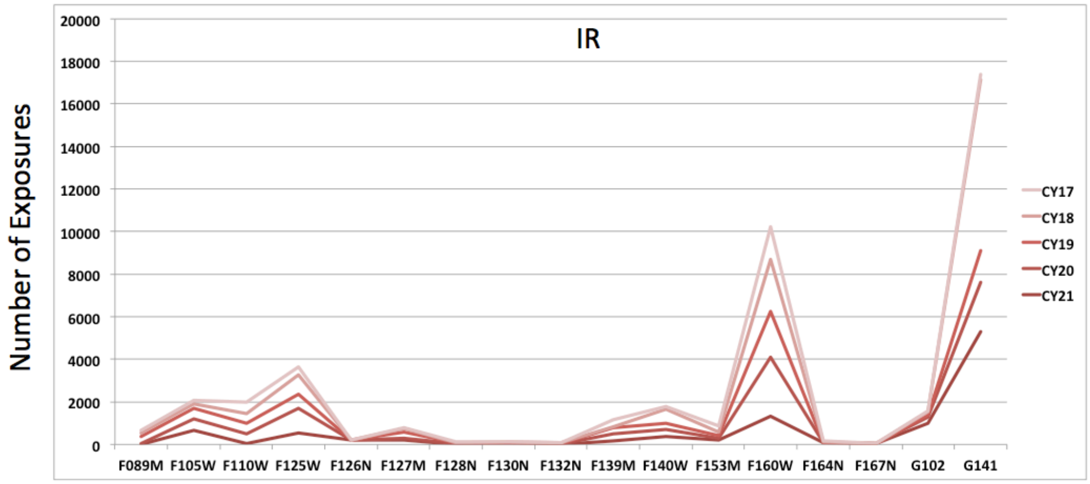


**Fig. 2:** GOs filter usage from Cycle 17 to 21 for all the filters available on the IR channel. Data are measured in number of exposures.

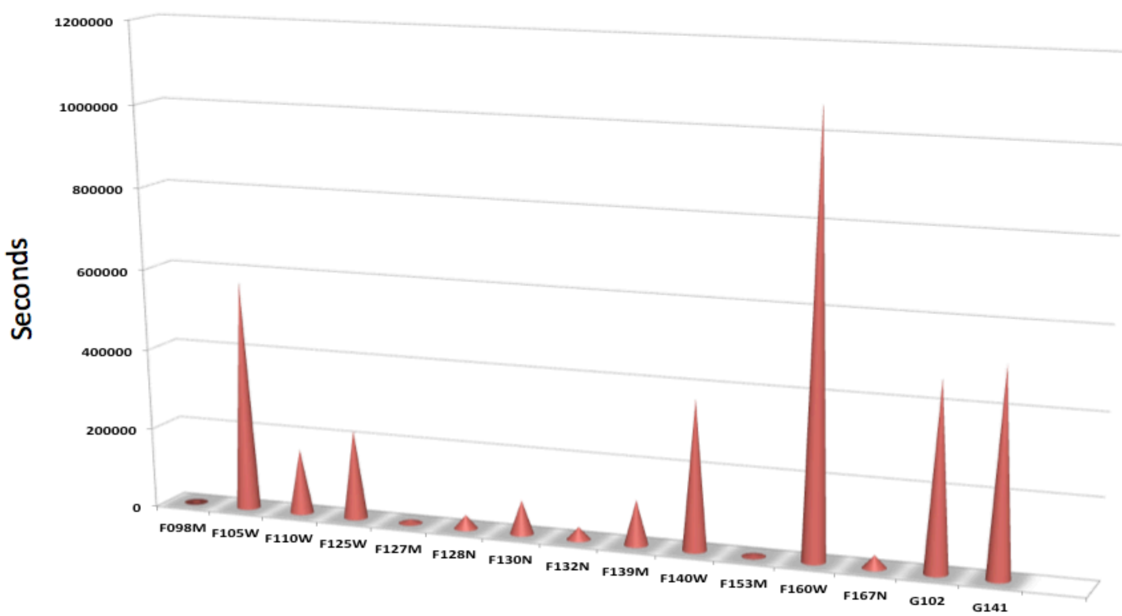


**Fig. 3:** IR channel GOs filter request for the only CY22. Only the filters requested by GOs are shown. Data are expressed in number of seconds.

## 2. Calibration Requirements

The WFC3 calibration plan for CY22 was built to support the variety of observational modes requested by the GOs, and to monitor the performances of both WFC3 channels. The 32 calibration activities are grouped in eight different categories: UVIS Detectors, IR Detector, CTE Characterization and Calibration, Characterization of IR Persistence, WFC3 Photometric Performances, WFC3 Grisms, WFC3 Flatfields Calibrations and Astrometric Calibrations (Table 3).

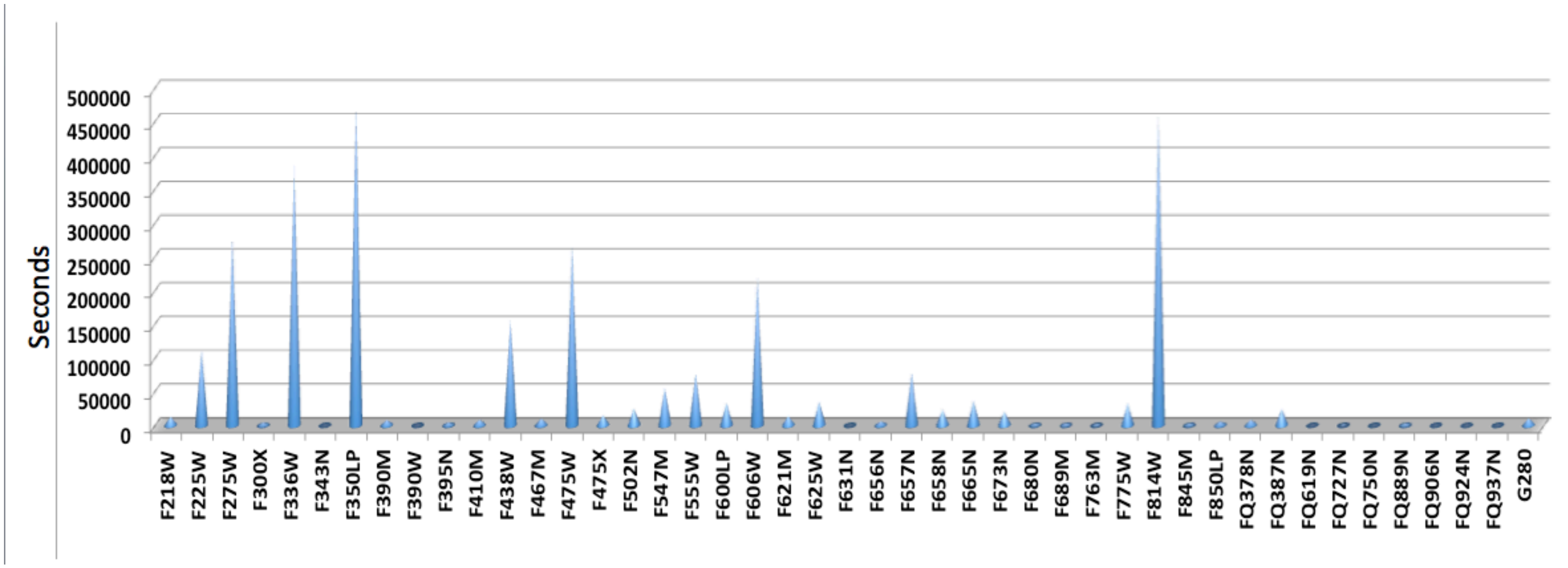


**Fig. 4:** Same as Figure 3, but for the UVIS channel.

## CY22 Proposed 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 | 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 | | WFC3 IR grisms wavelength calibration stability and calibration | 4 | 0 |
| IR dark monitor | 0 | 95 | | WFC3 IR grisms flux/trace calibration stability and calibration | 4 | 0 |
| IR linearity monitor | 0 | 9 | | WFC3 UVIS grism wavelength calibration stability and calibration | 2 | 0 |
| IR gain monitor | 0 | 16 | | WFC3 UVIS grism flux calibration** | 2 | 0 |
| UVIS CTI monitor (EPER) | 0 | 12 | | UVIS Pixel-to-Pixel QE Variations via Internal Flats Monitor | 0 | 51 |
| UVIS CTE monitor (star cluster) | 6 | 0 | | UVIS internal flats | 0 | 13 |
| WFC3/UVIS CTE in subarrays | 0 | 42 | | IR internal flats | 0 | 18 |
| Characterization of UVIS traps with CI** | 0 | 36 | | CSM monitor with earth flats | 0 | 200 |
| Refining the persist. model in the IR detector | 12 | 12 | | Astrometric Validation of WFC3/UVIS filters | 18 | 0 |
| Short term persistence | 3 | 3 | | High precision calibration of WFC3/UVIS geometric distortion (CAL-13929) | 10 | 0 |
| Persist. after worst actors** | 0 | 50 | | | | |
| Persist. after non-scanned grism obs.** | 3 | 4 | | | | |

CY22 Total external orbits=113;     Total internal orbits=1620

**Table 3:** List of the CY22 calibration activities. For each program the number of used external and internal orbits is listed. Programs belonging to the same calibration category are grouped together. Different colors in the table correspond to different categories: UVIS Detectors is in light blue, IR Detector in red, CTE Characterization and Calibration in yellow, Characterization of IR Persistence in orange, WFC3 Photometric Performances in green, WFC3 Grisms in purple, WFC3 Flatfields Calibrations in dark blue, and Astrometric Calibrations in grey.

# 3. UVIS Detector

One of the main goals of CY22 calibration plan is to continue to calibrate and monitor the properties of the instrument. The health of the two UVIS CCDs is checked using 1058 internal orbits. This dataset is also used to obtain important calibration files such as darks and hot pixels maps. Observations have been organized as follow:

1. **UVIS Anneal:** 85 internal orbits, whose cadence is synchronized with the other HST instruments, are allocated to perform an anneal every month. During the anneal the UVIS detectors are warmed up to ~20C. This procedure restores a large fraction of hot pixels to normal levels. In previous cycles IR darks were collected at the end of each anneal to verify the status of the IR channels. Since in CY21 we stop warming up the IR channel in CY22 we have dropped the IR darks. This has the advantage to reduce the number of Channel Select Mechanism (CSM) movements.

2. **UVIS Bowtie Monitor:** 130 internal orbits are used to mitigate the hysteresis that affects the UVIS channel. The Bowtie monitor comprises a series of unsaturated and saturated internal-flats.

3. **UVIS CCD daily monitor:** 637 internals orbits are used to perform a daily monitoring of the CCDs behavior using a series of dark and biases. The data provide updated darks and hot-pixels maps.
4. **UVIS CCD un-flashed monitor:** 48 internals orbits are used to assess how well post-flash is mitigating CTE with time using a series of un-flashed darks
5. **UVIS post-flashed monitor:** 60 internal orbits are used to monitor the stability of the post-flash LED with time.
6. **UVIS CCD gain stability:** 18 internal orbits are used 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.

## 4. IR Detector

The health of the IR detector is monitored through 120 internal orbits. As for the UVIS monitoring programs, this dataset is also used to obtain calibration files. The IR internal orbits have been divided as follow:

1. **IR Dark Monitor**: 95 internal orbits are used to obtain IR dark calibration files. The number of orbits is dictated by the observing modes requested by GOs.
2. **IR Linearity Monitor:** 9 internal orbits. A series of saturated internal-flats are used to monitor the IR non-linearity and update the calibration files.
3. **IR Gain Monitor:** 16 internal orbits are used to verify the stability of the IR channel gain via a series of internal flats. Different orbits are required to avoid persistence effects.

## 5. CTE Characterization and Calibration

The harsh conditions in space progressively degrade the charge transfer efficiency (CTE) of CCDs. We have assigned 6 external and 90 internal orbits to monitor the UVIS CTE performances change with time, and mitigate the effects degrading CTE on science data, for example using post-flash. To support these efforts we ask:

1. **UVIS CTI Monitor:** 12 internal orbits are used for an every other month measurement of the CTE via Extended Pixel Edge Response (EPER).
2. **UVIS CTE Monitor with Star Clusters:** 6 external orbits are used to observe stellar fields characterized by different crowding and background (2 fields in 47 Tuc and 1 in NGC 6791) to calibrate the photometric CTI corrections, and verify the impact of CTE on astrometry.
3. **Post-flash Calibration in Subarrays:** 42 internal orbits of biases, plus short and long darks are used to calibrate subarrays observations acquired with post-flash.
4. **Characterization of UVIS Traps with Charge Injection:** 36 internal orbits with charge-injected bias to monitor the length of the CTE trails. This information will be incorporate into the pixel-based algorithm for CTE mitigation (Anderson & Bedin 2010).

## 6. Astrometric Calibration

WFC3 is affected by sever geometric distortion, that cause a displacement of celestial sources from their real position on the sky up to about 5” in the UVIS channel and 2” in the IR channel respectively (Kozhurina-Platais et al. 2009a,b). Geometric distortion solutions have been derived from observations of the globular cluster Omega Cen for 13 UVIS and 8 IR filters (Kozhurina-Platais et al. 2012). For all the remaining filters the solution for the F606W filter (for UVIS) or F160W (for IR) are used. In CY22 a total of 28 external orbits is used to:

1. **UVIS Geometric Distortion:** 18 external orbits are used to verify the quality of the geometric distortion solution for all the WFC3/UVIS filters, and improve the solution for three filters whose current solution has residuals > 0.1 pixels.
2. **High Precision Astrometry:** 10 external orbits are used to map and remove residuals structures from the high precision geometric distortion solution derived from spatial scan. At the moment residuals are at the level of 5 millipixels.

## 7. Characterization of IR Persistence

Over the past Cycles the WFC3 team has developed a model and an internal pipeline to generate calibration files to correct individual IR exposures affected by persistence Long et al. 2011, 2013a, 2013b). During this cycle a total of 18 external and 69 internal orbits is used to:

1. **Improve the IR Persistence Model:** 12 external + 12 internal orbits are used to improve our current model for persistence.
2. **Short Term Persistence:** 3 external + 3 internal orbits are used to determine the amount of persistence in the first 10-150 sec after an exposure.
3. **Persistence after non-scanned repetitive grism observations:** 3 external + 4 internal orbits are used to determine whether non-scanned repetitive grism observations should be declared worst actors.
4. **Persistence after Worst Actors:** 50 internal orbits are used to determine whether the special observations in the Worst Actor category are well-described by our Persistence model.

## 8. WFC3 Photometric Performance

One of the most appreciated qualities of WFC3 is the stability of its photometric performance. In CY22 we are using 50 external orbits and 1 internal orbit to

1. **Monitor WFC3 Contamination and Stability:** 18 external orbits are used to measure the photometric throughput of WFC3 in a series of key filters every 5 weeks to validate the instrument throughput stability (11 orbits) and characterize the wavelength dependency of the throughput decrease observed at optical wavelengths (7 orbits).
2. **UVIS Shutter Characterization:** 3 external +1 internal orbits are needed to characterize the performances of the shutter blades. In particular we are testing the stability of the blades after 5 years of operation; check the behavior of both shutter blades in short and long exposures, and check for any shading effect by the shutter.
3. **Photometric repeatability of scanned direct imaging:** 4 external orbits are used to measure the repeatability of photometry of scanned direct IR images versus the performance for staring mode photometry.

4. **WFC3 UVIS and IR photometry:** 21 external orbits are requested to check photometric zero-points for all WFC3 UVIS and IR filters.
5. **WFC3 IR observations of red CALSPEC stars:** 3 external orbits are requested to enable direct calibration of Zeropoints at effective wavelengths that are closer to non-stellar sources (i.e. galaxies and SN).

## 9. WFC3 Grisms

Over the past 5 cycle the WFC3 team has invested a big effort in deriving the wavelengths and flux calibrations for the WFC3 grisms. Calibrations are determined fpr several positions across the detectors. InCY22 we have designed 4 small programs to continue to monitor the performance of the WFC3 grisms: A total of 12 external orbits used to:

1. **UVIS Grism: Flux Calibration:** 2 external orbits are used to monitor the UVIS grism flux in chip2 and calibrate its flux in chip 1.
2. **UVIS Grism: Wavelength Calibration & Stability:** 2 external orbits are used to monitor the UVIS grism wavelengths stability in chip2 and calibrate the wavelength in chip 1.
3. **IR Grisms: Flux Calibration:** 4 external orbits are used to improve the flux calibration for both the IR GRISMs
4. **IR Grisms: Wavelength Calibration & Stability:** 4 external orbits are used to improve the wavelength calibration for both the IR GRISMs

## 10. WFC3 Flatfield Calibrations

Internal flatfields are used to monitor the health of all the WFC3 filters. The WFC3 team is using 282 internal orbits to:

1. **CCD Anomalous QE pixels:** 51 internal orbits are used to monitor a population of UVIS pixels with anomalous QE.
2. **UVIS Internal Flats:** 13 internal orbits are used to monitor the health of the UVIS filters via int-flats
3. **IR Internal Flats:** 18 internal flats are used to monitor the health of the IR filters via int-flats.
4. **CSM Monitor with Earth Flats:** 200 internal orbits are used to monitor the health of the CMS mechanism by observing the bright earth.

## 11. Data, Analysis and Results

As in previous cycles all analysis and results from the Cycle 22 Calibration Program will be described in Instrument Science Reports (ISRs) and will be available on the WFC3 web site at http://www.stsci.edu/hst/wfc3/documents/ISRs/. Updated reference files will be provided to the scientific community when appropriate.

A detailed description of all the CY22 WFC3 Calibration Proposals can be found at the url http://www.stsci.edu/hst/wfc3/calibration/CY22/CY22_cal_program.pdf. As for any other HST observation, the PhaseII's of these Calibration Proposals are public and can be consulted at http://www.stsci.edu/hst/scheduling/program information. Proposal IDs, titles and direct links to the proposal status can be found at the url http://www.stsci.edu/hst/wfc3/calibration/CY22

**Aknowledgments:** Elena Sabbi is grateful to Knox Long and Vera Kozhurina-Platais for reviewing this ISR and largely contributing in improving it

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