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Calibration Status of the Advanced Camera for Surveys

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Abstract. The Advanced Camera for Surveys is producing spectacular science results that require careful instrument calibration. This article provides an overview of recent calibration highlights and calibration plans for Cycle 14.

1. Introduction

The Advanced Camera for Surveys (ACS) is operating nominally at the time this review is being written. ACS instrument performance with HST in two-gyro mode is indistinguishable from its performance in three-gyro mode (see Sembach et al., this volume and references therein). The ACS Calibration Team at STScI and ST-ECF continually monitors instrument performance through its ongoing instrument calibration activities, and updates the *ACS Instrument Handbook* (Gonzaga et al. 2005) released with the *HST Call for Proposals* at the beginning of each observing cycle.

Cycle 14 brings some new challenges for the calibration of the instrument, as there is somewhat increased demand for Solar-Blind Channel (SBC) observations and prism/grism observations now that STIS is no longer operating. On behalf of all the people involved in ACS calibration activities, this article contains a brief overview of the instrument status and calibration program for Cycle 14. More information about specific calibrations can be found in accompanying articles by ACS Calibration Team members and Guest Observers in the astronomical community. Instrument Science Reports (ISRs) that provide detailed descriptions of the calibration procedures and analyses can be found on the ACS ISR web page:

http://www.stsci.edu/hst/acs/documents/isrs

Information about calibration activities in previous cycles, including the titles and program numbers of calibration programs, can be found at

http://www.stsci.edu/hst/acs/analysis/calib_plan

In preparation for Cycle 14, the ACS Calibration Team reviewed previous Cycle 13 calibration programs and identified activities that needed to be continued into Cycle 14. It also identified new calibration needs that were not covered by the existing programs. As part of this exercise, the team trimmed the sizes of some routine calibration programs by consolidating and reducing the cadence of observations whenever possible. Table 1 contains a summary of the number of ACS calibration orbits allotted for Cycle 14. With contingency, the total orbit request for the primary calibration program is 1320 orbits (67 external, 1253 internal).

For comparison, the Cycle 13 ACS calibration program required 70 external orbits and 1138 internal orbits. Thus, the number of orbits required for the Cycle 14 calibration program is comparable to that in Cycle 13. Routine monitoring programs take less time than before, but special calibrations added in this cycle require more orbits than the special programs in the previous cycle (see Tables 2-4 in the following sections). A small amount of

Table 1: Cycle 14 ACS Calibration Orbit Summary

Cycle 14	Orbits		
	External	Internal	Outsourced[a]
Total Time (routine + special programs)	62	1142	11
With Contingency	67	1253	11

[a]Two programs (PI = Dolphin): ACS Zero-Point Verification (#10621) and ACS Photometric Calibration from Faint Standards (#10622).

contingency time (8-10%) is included in the calibration program for each cycle to account for unforeseen calibration needs.

The 11 outsourced orbits awarded in Cycle 14 by the HST Time Allocation Committee are included in Table 1 for completeness. Calibration outsourcing is an important component of the calibration program since it allows Guest Observers to obtain calibrations that are not otherwise covered by the primary calibration plan defined by the STScI ACS Team. We encourage Guest Observers to propose calibration GO programs when they need more precise calibration data than the standard instrument calibration activities provide, or when they need calibrations for an uncalibrated mode of operation. Requests and suggestions for calibrations to include in the standard ACS calibration plan are also welcomed and will be given full consideration within the context of the overall calibration plan for the subsequent cycle of observations.

2. Cycle 14 Routine Monitoring Programs

Various routine monitoring and maintenance programs are required to track the performance of the instrument and ensure that observers have the most up-to-date calibrations available to reduce their data. Examples of routine calibrations for Cycle 14 include maintaining accurate flat field, dark, and bias frames, monitoring photometric throughput and stability, and tracking CCD charge transfer efficiency (CTE). A summary of the routine calibration programs for Cycle 14 is given in Table 2, which lists the proposal number, principal investigator, program title, frequency of observations, and the number of external and internal orbits required during the cycle. These programs are described briefly below.

Table 2: Cycle 14 Routine Monitoring Programs

Program ID	PI	Title	Frequency	Orbits Ext.	Orbits Int.	Note
10729	Sirianni	CCD Daily Monitor	4/week	0	840	Dark, bias creation
10730	Chiaberge	External CTE Monitor	6 months	9	0	CTE loss calibration
10732	Mutchler	Internal CTE Monitor	yearly	0	35	Check against ground
10733	Cox	CCD Hot Pixel Annealing	monthly	0	143	Includes monthly CTE
10734	Cox	CCD Post-Flash Verification	yearly	0	4	Tracks capability only
10735	Cox	SBC MAMA Recovery	as needed	0	4	After irregular safing
10736	Maiz	UV Contamination Monitor	6 months	4	2	SBC, HRC tracking
10737	Mack	CCD Stability Monitor	3 months	13	0	L-flat, distortion, photometry
10738	Mack	Earth Flats	weekly	0	52	Tracks coronagraphic spot
10739	Bohlin	Internal Flat Fields	4 months	0	44	SBC components once
10740	Bohlin	Photo-Spectrophot. Abs. Cal.	yearly	7	0	Filter throughputs, QE
Total (Cycle 14 routine monitoring programs)				33	1124	

2.1. Darks and Biases

The CCD Daily Monitor program (#10729) measures the read-noise and dark current in the ACS CCDs as a function of time. It also tracks the growth of hot pixels. `CALACS` uses the reference files generated by this calibration program for every CCD science exposure it processes, so it is essential that the properties of the darks and biases be updated frequently. As a result, the number of orbits required for this program accounts for the vast majority of ACS internal calibration orbits. For Cycle 14, the default gain setting for the Wide-Field Channel (WFC) has been changed to `GAIN=2` e^{-}/ADU, so we will be obtaining dark and bias data to support this new gain setting as well as other supported gain settings. See Lucas et al. (this volume) and Mutchler et al. (this volume) for more information on the automated procedures used to process ACS dark and bias frames for use in `CALACS`. Recent relevant ISRs include:

- *SBC Dark and Cumulative Images*, ACS ISR 2004-14, by C. Cox
- *Bias and Dark Calibration of ACS Data*, ACS ISR 2004-07, by M. Mutchler et al.

2.2. CCD Hot Pixel Annealing

The CCD Hot Pixel Annealing program (#10733) reduces the number of non-permanent hot pixels on the ACS CCDs by warming the detectors to temperatures of +20° C for 6 hours before returning to the normal operating temperatures (-77° C for the WFC and -80° C for the HRC). These anneal times are a factor of two shorter than in previous cycles; program #10453 in Cycle 13 demonstrated the effectiveness of reducing the anneal time from 12 hours to 6 hours. Reduced anneal times make scheduling easier. At the current hot pixel threshold of 0.08 e^{-} pix^{-1} sec^{-1}, the anneals typically eliminate $\sim$ 82% of the non-permanent hot pixels on the WFC and $\sim$ 87% on the HRC (see Sirianni et al., this volume, for more information). Data from this program are also used in the monitoring of CTE (internal) and the tracking of dark levels.

2.3. Flat Fields

Several routine monitoring programs provide information about the flat field properties of the ACS CCDs as measured using both external observations (stellar photometry and bright Earth illumination) and internal lamp exposures. The CCD Stability Monitor program (#10737) is the primary source of low-frequency flat fields (L-flats). Regular observations of the same star field within the globular cluster 47 Tuc provide L-flats that have an accuracy of $\sim$ 1% over the full fields of view of the HRC and WFC. The observations track changes in relative sensitivity with an accuracy of $\sim$ 0.1% per year. This program also monitors variations in the CCD geometric distortion corrections with time.

The Earth Flats program (#10738) cross-checks the L-flats created by the CCD Stability Monitor and tracks any changes on time scales shorter than the three month interval of the CCD Stability Monitor by obtaining exposures of the bright Earth during occultations. This program also determines the coronagraphic spot position to better than 1 pixel accuracy.

The Internal Flat Field (#10739) program uses the internal tungsten lamp to assess the stability of the pixel-to-pixel flat fields (P-flats) in several HRC/WFC filters (F435W, F625W, F814W). In Cycle 14, new P-flats will be obtained for the six SBC filters and the SBC prisms (PR110L and PR130L). In all cases, the goal is to produce P-flats accurate to better than 1%.

We comment on flats for polarization and ramp filter observations below in §§5 and 6. Further information about flat fields can be found in the article by Mack et al. (this volume). Recent ISRs related to routine flat field creation and monitoring include:

- *SBC L-Flat Corrections and Time-Dependent Sensitivity*, ACS ISR 2005-13, by J. Mack et al.
- *Earth Flats*, ACS ISR 2005-12, by R. Bohlin et al.
- *The Internal CCD Flat Fields*, ACS ISR 2005-09, by R. Bohlin & J. Mack
- *Flats: SBC Internal Lamp P-Flat*, ACS ISR 2005-04, by R. Bohlin & J. Mack
- *ACS Coronagraphic Flat Fields*, ACS ISR 2004-16, by J. Krist

2.4. Charge Transfer Efficiency

The ACS CCD detectors degrade with time due to radiation damage. One effect of this degradation is a decrease in CTE. Several monitoring programs track the level of CTE and its change with time. The External CTE Monitor (#10730) obtains images of 47 Tuc with half-field of view dithers to estimate photometric losses due to CTE as a function of time and position on the CCDs. The goal of this program is to provide corrections for photometric measurements to an accuracy of 1-2%. An independent check on the CTE is provided by data obtained as part of the CCD Stability Monitor program. The ACS Team is currently investigating procedures for mitigating the effects of CTE in the future, including changing the temperature at which the CCDs operate (Cycle 14 special program #10771).

The Internal CTE Monitor (#10732) uses internal tungsten lamp data to trend the overall CCD radiation damage. It tracks both parallel and serial CTE performance. The data for this program are not used directly in the calibration of ACS observations.

The CCD Post-Flash Verification program (#10734) occasionally tests the ability to illuminate the ACS CCDs with a light emitting diode in a repeatable fashion. This capability may be needed in the future to improve CTE for some exposures (at the expense of adding noise to the data). The post-flash is not yet necessary or available for science observations.

A description of the results from the ACS CTE monitoring programs is given by Chiaberge et al. (this volume). Recent ISRs related to CTE include the following:

- *Internal Monitoring of ACS Charge Transfer Efficiency*, ACS ISR 2005-03, by M. Mutchler
- *Time Dependence of ACS WFC CTE Corrections for Photometry and Future Predictions*, ACS ISR 2004-06, by A. Riess & J. Mack
- *Elevated Temperature Measurements of ACS Charge Transfer Efficiency*, ACS ISR 2004-04, by M. Mutchler & A. Riess

2.5. Photometric/Spectrophotometric Throughput and Contamination Monitoring

The absolute sensitivity and repeatability of ACS photometric and spectrophotometric observations are calibrations that require monitoring on a yearly timescale. The Photo-Spectrophotometric Absolute Calibration monitor (program #10740) establishes the relative magnitudes of three primary white dwarf calibrators to 0.1% accuracy and checks repeatability of the WFC and HRC filter throughputs to 0.2% accuracy using observations of single-star flux standards. These measurements are needed to refine the filter bandpasses. A portion of the time in this program is also being used to cross-calibrate the ACS prism, grism, and F850LP filter with NICMOS and STIS. Changes in sensitivity and the CCD quantum efficiency as a function of time are are also tracked by the CCD Stability Monitor (program #10737), which observes large numbers of stars in 47 Tuc.

A comprehensive paper describing the ACS photometric calibration and the photometric transformations to other photometric systems has been completed recently by Sirianni et al. (2005). The paper includes transformation coefficients for converting ACS HRC/WFC photometry to WFPC2 and the Landolt UBVRI photometric systems. It also contains information about ACS aperture corrections for point source photometry.

The UV Contamination Monitor program (#10736) tracks the throughputs in the six SBC filters (F115LP, F122M, F125LP, F140LP, F150LP, F165LP), the SBC prisms (PR110L, PR130L), three HRC UV filters (F220W, F250W, F330W), and HRC PR200L. These results are cross-referenced to previous STIS observations of the same cluster (NGC 6681). The goal is to track the UV photometry to 1% accuracy to monitor small changes in the throughput on timescales of ~ 6 months.

Recent ISRs related to ACS sensitivity and UV contamination monitoring include:

- *SBC L-Flat Corrections and Time-Dependent Sensitivity*, ACS ISR 2005-13, by J. Mack et al.
- *The Photometric Stability of ACS: Revisiting the Hubble Deep Field*, ACS ISR 2004-17, by A. Riess
- *Detector Quantum Efficiency and Photometric Zero Points of the ACS*, ACS ISR 2004-08, by G. De Marchi et al.
- *Results of UV Contamination Monitoring of the ACS*, ACS ISR 2004-05, by F. Boffi et al.

2.6. SBC MAMA Recovery

The SBC MAMA Recovery program (#10735) is used to turn on the ACS MAMA and return it to its normal operational state after an anomalous shutdown. This program is invoked only when needed (less than once per year).

3. Cycle 14 Special Calibration Programs

Several special calibration programs complement the Cycle 14 routine calibration programs described above. These special programs, which are listed in Table 3, provide basic calibrations for the SBC and ramp filters, information about the UV narrow-band red leak, and the dependence of CTE and QE on CCD temperature. Results from this latter test (program #10771) will be used in assessing the need for installation of the Aft Shroud Cooling System during the next Hubble servicing mission.

Table 3: Cycle 14 Special Calibration Programs

Program ID	PI	Title	Orbits Ext.	Orbits Int.	Note
10722	Maiz	SBC Geometric Distortion	6	4	Basic calibration
10731	Chiaberge	UV Narrow-Band Red Leak	2	0	Responds to early failed cal
10741	Suchkov	Continuum L-Flats (Ramps)	3	0	Basic calibration
10742	Fruchter	Ramp, Grism Wavelengths	4	0	Responds to early failed cal
10743	Larsen	Improved Wavelengths (SBC Prism)	2	2	QSO Lyα lines (1400-1800Å)
10771	Sirianni	CTE/QE Temperature Dependence	12	12	ASCS support test
Total (Cycle 14 special programs)			29	18	

A few special programs from Cycle 13 were completed recently; they are listed in Table 4. Some of these were functional checks for capabilities to be used only if needed (programs #10449, 10450), and others improved calibrations for the polarizers and prisms (programs #10378, 10391). The Short Annealing Test (program #10453) verified the effectiveness of using 6 hour anneals (see §2.2).

Table 4: Cycle 13 Special Calibration Programs

Program ID	PI	Title	Orbits Ext.	Orbits Int.	Note
10378	Biretta	Polarization Calibration	12	0	Last visit in July 2005
10391	Larsen	Wave, Flux for Prisms (SBC and HRC)	1	11	Last visit in August 2005
10449	Cox	SBC Filter Wheel Checkout	0	7	Use program only if needed
10450	Sirianni	Functional Test of MEB2 Switch	0	2	Use program only if needed
10453	Sirianni	Short Annealing Test	0	0	Adopted for routine use
10720	Riess	Monochromatic PSF in the Red	1	0	Recently submitted
Total (Cycle 13 special programs)			13	20	

4. SBC Calibrations

SBC observations currently account for only $\sim 3\%$ of the ACS observing time, but observations in this channel have received more attention since STIS shut down. The Cycle 14 SBC Geometric Distortion program (#10722) is intended to improve the geometric distortion solution in the ACS/SBC imaging modes and the PR130L prism mode. The geometric distortion correction is needed to upgrade the SBC L-flats to a level approaching that of the CCD L-flats. Several special calibration programs designed to improve the SBC prism wavelengths (#10743, 10391) enhance previous calibrations. In Cycle 14, prism observations account for about one quarter of the SBC observing time. See the accompanying articles in this volume by Cox and Larsen for more information about SBC calibration activities.

5. Polarized Filters

Polarization calibration activities (such as Cycle 13 program #10378) have been used to characterize the ACS polarizers and their possible uses. A series of ISRs describing the polarizers describes recent progress in calibrating the polarized filters.

- *ACS/HRC Polarimetry Calibration IV. Low-Frequency Flat-Fields for Polarized Filters*, ACS ISR 2005-10, by V. Kozhurina-Platais & J. Biretta
- *ACS/HRC Polarimetry Calibration III. Astrometry of Polarized Filters*, ACS ISR 2004-11, by V. Kozhurina-Platais & J. Biretta
- *ACS Polarization Calibration II. The POLV Filter Angles*, ACS ISR 2004-10, by J. Biretta & V. Kozhurina-Platais
- *ACS Polarization Calibration I. Introduction and Status Report*, ACS ISR 2004-09, by J. Biretta et al.

6. Grism/Prism Spectroscopy and Ramp Filters

In Cycle 14, prism/grism spectroscopy accounts for approximately one tenth of the WFC observing time and one-quarter of the HRC and SBC observing time. The ST-ECF is responsible for the calibration of the ACS spectroscopic modes. Work continues on characterizing both the wavelength solutions and sensitivities of these modes. Recent ISRs include:

- *Updated Wavelength Calibration for the WFC/G800L Grism*, ACS ISR 2005-08, by S. Larsen & J. Walsh
- *Flat-Field and Sensitivity Calibration for ACS G800L Slitless Spectroscopy Modes*, ACS ISR 2005-02, by J. Walsh & N. Pirzkal

The ST-ECF spectral extraction software, `aXe`, is the primary software used to manipulate ACS slitless spectroscopy images. The most current version of this software (v1.5) can be linked to from the ACS web page. See the accompanying article in this volume by Walsh et al. for a description of the software and its uses.

Two Cycle 14 special programs will provide updated calibrations for the ACS ramp filters. Program #10742 will calibrate the throughputs of the ramp filters as a function of wavelength by obtaining observations of a flux standard with the filters crossed with the grism. This should also calibrate the zeroth order of the grism, which may allow some users to avoid having to obtain additional direct images of the fields they observe with the grism. Program #10741 will provide continuum L-flats for the ramp filters, which will improve the characterization of the total filter transmissions.

7. Coronagraphy

Coronagraphic observations account for roughly 3-4% of ACS observing time. They depend strongly on the pointing stability of the telescope and the ability to flat field detector artifacts. These issues are discussed in the following two ISRs. Observers should note that there is no appreciable difference in the quality of coronagraphic observations between two-gyro mode and three-gyro mode.

- *ACS Coronagraph Performance in Two-Gyro Mode*, ACS ISR 2005-05, by C. Cox & J. Biretta
- *ACS Coronagraphic Flat Fields*, ACS ISR 2004-16, by J. Krist

8. Point Spread Function

The ACS point spread function (PSF) depends on wavelength. To date, there has been only a limited amount of information about the PSF shape. Encircled energies are given by Sirianni et al. (2005), and the shape and stability of the PSF has been documented in the following ISRs:

- *Characterization of the ACS/HRC Point Spread Function in Two-Gyro Mode*, ACS ISR 2005-11, by M. Sirianni et al.
- *Two-Gyro Pointing Stability of HST Measured with ACS*, ACS ISR 2005-07, by A. Koekemoer et al.
- *Multi-Filter PSFs and Distortion Corrections for the HRC*, ACS ISR 2004-15, by J. Anderson & I. King

Several talks at this workshop also addressed the issue of ACS PSFs.

The ACS Calibration Team is using Cycle 14 special calibration program #10720 to characterize the monochromatic PSF of the WFC in the red using a combination of the F850LP filter and several ramp filters. The purpose of this program is to improve the precision of photometric measurements obtained with the F850LP filter.

9. Astrometry

With the advent of Guide Star Catalog 2, it should be possible to improve the absolute astrometric solutions for ACS images by roughly an order of magnitude over current solutions. An accuracy in the range of 0.1-0.3″may be achievable for fields containing sufficient numbers of identifiable guide stars. The following ISR documents the technique for achieving an astrometric accuracy comparable to the resolution of the telescope.

- *Demonstration of a Significant Improvement in the Astrometric Accuracy of HST Data*, ACS ISR 2005-06, by A. Koekemoer et al.

10. WFC CCD Gain Change for Cycle 14

The new default gain setting for the WFC in Cycle 14 is `GAIN=2`. This change helps to alleviate image ghosts caused by electrical cross-talk, which is documented in the following ISRs:

- *Cross-Talk in the ACS WFC Detectors II. Using* `GAIN=2` *to Minimize the Effect*, ACS ISR 2004-13, by M. Giavalisco
- *Cross-Talk in the ACS WFC Detectors I. Description of the Effect*, ACS ISR 2004-12, by M. Giavalisco

11. Documentation and Web Site Updates

Several updates to ACS documentation should make it easier for observers to find information about ACS. First, the *ACS Instrument Handbook* (Gonzaga et al. 2005) has been reduced in length by about 15% without loss of content by consolidating information and moving some of the ACS calibration plan material to the ACS web site. The index for the handbook has also been updated, and a series of summary tables at the front of the handbook have been added to make it easier to find basic information about the instrument and its supported modes of operation. The *ACS Instrument Handbook* was released with the Cycle 15 *Call for Proposals*.

A short update to the *ACS Data Handbook* is planned (Pavlovsky et al. 2006). The update will include minor corrections to wording and syntax of some of the examples, as well as clarification of some of the text related to prism/grism reductions. The updated handbook is expected to be released in early 2006.

ACS long term usage statistics are now being charted on the STScI metrics web page at *http://www.stsci.edu/hst/metrics/SiUsage/ACS_LT*. This page contains both graphical and tabular information about requested ACS modes, filters, and exposure times.

Acknowledgments. Calibration of the ACS is truly a team effort. I thank the members of the ACS Calibration Team for their dedicated efforts to specify and conduct the ACS calibration program described in this article. I thank the PIs of the calibration programs listed in Tables 2-4 for their descriptions of the calibration programs. I am particularly grateful to Ron Gilliland, the ACS calibration lead, for his willingness to distill a large amount of calibration information and organize it into tabular form.

References

Gonzaga, S., et al. 2005, *ACS Instrument Handbook*, Version 6.0, (Baltimore: STScI)

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