Instrument Science Report ACS 2019-07

Advice for Planning ACS Observations

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ABSTRACT

When planning Advanced Camera for Surveys (ACS) observations, there are a number of things one should always check and consider, both in Phase I proposing and later in Phase II observing program development and design. This ISR lists many of these topics here in one place, together with references, and introduces up-to-date information via this report and a new web page regarding current best practices for proposing and observing with the ACS on the Hubble Space Telescope.

1. Introduction

Many issues may arise during the preparation of observing programs. In order to help forestall problems where non-optimal program design is proposed and/or implemented, this ISR documents some issues and standard references which users should consider when proposing (Phase I) and planning accepted observations (Phase II) using the Advanced Camera for Surveys (ACS). Also see the ACS Observing Advice web site.

2. Useful HST Phase I and Phase II User Documentation

https://hst-docs.stsci.edu

The latest ACS documentation including the ACS Instrument Handbook, the ACS Data

Handbook, and ACS ISRs, etc. may be accessed from here:

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

The on-line HDOX-format document that is the equivalent of this ISR is always more likely to be up-to-date than this possibly more static ISR. It is the ACS Observing Advice web page which is available indirectly via the ACS web pages above, or more directly at

https://hst-docs.stsci.edu/acsoam .

It is always important to read each new cycle's documents carefully, as some practical and policy items may change from cycle to cycle, and to look at the latest ISRs dealing with any given topic as the instrument continues to age and evolve.

Please note that some topics appear in both the Phase I and Phase II-related sections of this paper. **Those appearing in the Phase I section are there because it is required that they be formally specified in the Phase I proposal if they will be needed in Phase II.** Although perhaps seemingly redundant, their additional appearance in the Phase II section is a reminder that they are even more critical there since the actual observations are generated from the Phase II specifications, and sometimes some additional details need to be considered or are required to go along with them in Phase II. The Phase I and Phase II documentation describes the level of detail that is required to be specified in each Phase.

3. Phase I Proposing Issues

Issues of concern in Phase I are nominally much fewer since less technical detail is required at this initial stage. This is covered more thoroughly and in a more up-to-date manner in the Phase I documents such as the Call for Proposals, Phase I Roadmap, and HST Primer for each new cycle, so the reader is referred to those documents for more details. The main focus of this document is on preparation of accepted ACS programs for Phase II. However, we choose to highlight a few specific topics here which are usually required to be requested in Phase I. Failure to request them in Phase I requires a subsequent scientific and technical justification to the STScI Telescope Time Review Board (TTRB). These requests may or may not be granted since the TTRB's intent is to follow any instructions and allocations from the TAC to the observers based on the TAC's review unless new and significant benefits still in keeping with the science approved by the TAC can be demonstrated by the changes requested. Among the most common of these sometimes forgotten or misunderstood items are **specification of coordinated parallel observations**, **LOW-SKY** or **SHADOW** requirements, Continuous Viewing Zone (**CVZ**), **timing requirements**, **ORIENT** requirements, **Bright Object Checking for ACS/SBC** observations, **special calibrations**, and **all items which fall within the broad category of "limited resources"** which **must be**

specifically proposed for in Phase I according to the Phase I documentation.

Coordinated Parallel Observations

Although they may seem an obvious thing to do in some cases, simultaneous parallel observations in other science instruments are a limited resource in terms of data volume, buffer storage, and buffer dumps. These factors can also affect the primary observations, and instrument use causes wear and tear on the equipment. As such, coordinated parallels must be justified scientifically as representing compelling science.

There are a variety of ways of observing in parallel. In particular, ACS/WFC and WFC3 in either the UVIS or IR channel are often used in parallel. Both the WFC3/UVIS and WFC3/IR fields of view are smaller and on-axis in the HST focal plane, and ACS/WFC's larger footprint is off-axis in the focal plane. It should be remembered that there is an appreciable difference in field size between ACS/WFC (202 x 202 arcsec and plate scale = 0.050 arcsec/pixel) versus WFC3/UVIS (162 x 162 arcsec and plate scale = 0.04 arcsec/pixel) and WFC3/IR (136 x 123 arcsec and plate scale = 0.13 arcsec/pixel).

When observing in parallel, in the simplest of cases, perhaps there is only a single pointing and no particular parallel target location (and therefore no particular ORIENT requirement) is desired. Or, complicating matters a bit more, perhaps there may be a specific parallel target in mind in which case a specific ORIENT requirement will be needed to have both the primary and parallel fields of view placed in the desired locations. Also, if trying to duplicate and repeat an earlier primary + parallel pointing, an exact ORIENT will need to be specified matching that of the earlier observation **as executed**, even if there was no ORIENT requirement on the original executed observation. **(Remember that ORIENT requirements need to be spelled out in the Phase I proposal in order to use them in Phase II.)** Some larger survey programs may employ mosaic tiling techiques with specific fixed ORIENT requirements on the primary instrument thus also creating a secondary tiled mosaic pattern with the parallel instrument's field of view. Taking that even a step farther, some programs then repeat the same observations roughly 6 months later at the opposite ORIENT angle when the resulting primary and parallel mosaics trade places, falling onto the field of view of the other instrument, albeit with a somewhat different footprint and coverage. Especially when covering a loose association of pointings within some area or considering total area covered in some larger survey of many different disconnected single fields, or when creating tiled mosaics, this difference in size can add up to a significantly larger amount of spatial coverage in ACS/WFC as opposed to either of the WFC3 channels.

When comparing ACS/WFC to WFC3/UVIS in terms of throughput at given wavelengths, it is also important to remember that ACS/WFC is typically more red-sensitive, whereas the greatest strength of WFC3/UVIS is in the bluer wavelengths. For more on a comparison of ACS/WFC and WFC3/UVIS calibration and photometry, please see Deustua and Mack 2017 (ACS ISR 2017-10) and references therein.

LOW-SKY or SHADOW Requirements and Sky Background Level Issues

If expecting or concerned about scattered light (zodiacal light, scattered light from Earth's limb at the beginning or end of orbits, etc.) in some or all filters which may cause a higher sky background than required to successfully achieve the scientific goals, consider using the ACS Exposure Time Calculator (ETC) to investigate these issues. By entering the target's coordinates and other vital information about the observations, one can estimate the maximum sky background levels due to such things as zodiacal light to see whether it is advisable to request a LOW SKY or SHADOW requirement. It should also be remembered that the effects of CTE (Charge Transfer Efficiency; Riess et al., WFPC2 ISR 1999-04; Riess et al., ACS ISR 2002-06) in ACS are greater at low sky background levels, so there is a potential trade-off to be considered here. Generally, any new exposure with a sky background level of less than roughly 20 electrons (e^-) is at risk of suffering from increased CTE effects, and the ACS ETC currently warns the user about this at the 20 electron level. This is most common in narrow- and/or medium-band filters, and very short exposures of less than about 300 seconds in any broad-band filter. However, although the ACS/WFC postflash can be used to increase sky background levels to mitigate CTE issues in such cases, unlike the WFC3/UVIS postflash, the ACS/WFC postflash is highly non-uniform, varying by a factor of about 2 across the ACS/WFC field of view (Ogaz et al. 2014, ACS ISR 2014-01; Miles et al. 2018, ACS ISR 2018-02.) The improvement is greatest in the central area of the detector. At present (December 2019), the ACS/WFC postflash is only recommended for use in very specific situations. Typically it is only currently recommended where mere detection is the goal, rather than in situations where uniform and accurate photometry is desired across the whole field of view. Use of it is typically discouraged when making a comparison to any other photometry which is more uniform across the field. LOW SKY and SHADOW are limited resources in terms of scheduling, and they will also cut down on available exposure time per orbit. However, if the low sky background is truly needed, this may help avoid using more exposure time and yet still having a sky background that is too high for the desired scientific purposes. **Again, LOW SKY and SHADOW must be proposed for in Phase I in order to use them in Phase II.**

Continuous Viewing Zone (CVZ)

Observations performed in either of the 2 (northern and southern) HST Continuous Viewing Zones (**CVZ**) can be very desirable and appear very worthwhile to the TAC because of their much greater observational efficiency. However, it should be remembered that these periods can vary in size and duration given the exact location of the target, and due to updated HST orbital ephemerides, some marginal **CVZ** periods may even disappear, though they may still be near-**CVZ** opportunities of greater than normal orbital duration. As such, **CVZ** observations are very limited resources, and should be investigated carefully before proposing for them. A more rigorous Phase II-style test proposal may help to test unusual or demanding situations, but that is still susceptible to later changes in the orbital ephemeris for HST, so one should be mindful of that possibility even though following the Phase I rules and advice in the standard Phase I documents (Call for Proposals, the Phase I Roadmap, and/or the HST Primer). Depending on the filters involved (redder filters are typically more susceptible), the risk of scattered light and higher background is also greater for **CVZ** observations. **The CVZ requirement must be proposed for in Phase I to be used in Phase II.**

Timing and ORIENT Requirements

Timing and **ORIENT** requirements may be essential for the successful design of some observations, but they are also limited resource requirements since they can greatly limit the times when the observations may be made. **As such, timing and ORIENT requirements must both be specified at least to the degree of detail required in Phase I proposals, though this may not always need to be as detailed as in Phase II.** More detailed information on the exact requirements for this can be found in the relevant Phase I documents such as the Call for Proposals, the Phase I Roadmap, and/or the HST Primer. Primary drivers for specifying timing requirements are observations of variable objects, observations of solar system objects, or any type of temporally variable source monitoring. ORIENT requirements may arise for various reasons. They may often be related to fitting some inherent source geometry on the sky cleanly into the field of view. They may also be used to avoid the bad effects of scattered light and artifacts of telescope optics and detector characteristics from bright stars near or on the field of view – things such as (1) avoiding diffraction spikes or CCD column bleeding from bright stars spilling onto the position of a target of interest in the field of view, (2) avoiding so-called "dragon's breath" from stars just off the field of view (Stankiewicz et al. 2008, HLA/ACS ISR 2008-01 and references therein; Porterfield et al. 2016, ACS ISR 2016-06, and references therein), (3) avoiding ORIENTs where a problematic star might fall on the edge of the inter-chip gap and cause a glint (Hartig 2002; Stankiewicz et al. 2008, HLA/ACS ISR 2008-01), and/or (4) avoiding ghosts shaped like the number "8" and other similar ghosts going diagonally across the field of view from bright stars being placed on the Amp D quadrant of the ACS/WFC detectors (Hartig et al. 2002). (The Amp D quadrant is the quadrant of the ACS/WFC which is farthest from the location of the WFC3 in HST's focal plane.) There is a web page regarding the many possible various ACS image anomalies at http://www.stsci.edu/hst/instrumentation/acs/performance/anomalies-and-artifacts .

Whether for primary observations or parallels, **ORIENTs are also required for attempts to match the exact pointing and field of view coverage of some earlier observations, as is the use of an aperture location that centers the coordinates on**

exactly the same spot as in the original observations. Note especially that if attempting to duplicate exactly the field of view of an earlier observation (including field corners) which had no ORIENT specification originally (whether ACS/WFC or ACS/SBC), one will need to find out the exact ORIENT at which that data was taken and the named aperture and coordinates which were specified for the primary observations. A look at the formatted version of the Phase II version of the program on the Program Information web page should show that information, including whether there were any dithers or offsets from the reference aperture location such as POS TARGs. (POS TARGs – short for "POSition TARGet" - are manually-specified Phase II target offset requirements on Exposure lines and are used for displacing the target position with respect to the reference aperture location. They are given for the x and y detector axes, and are specified in units of arcseconds.) **If very precise identical coverage is required, one may need to take care that unless the original aperture was either WFCENTER or one of the "-FIX" apertures, it is even possible that the reference aperture location such as "WFC" or "WFC1" or "WFC2" may have been shifted a bit over time by STScI to account for the location of any subsequent chip or detector defects which may have appeared later.** (Similar considerations apply to the WFC3 detectors.) The ACS WFCENTER aperture is simply the location of the intersection of lines drawn from the point of the 4 corners of the ACS/WFC detector, and the "-FIX" apertures are at invariant locations on the detectors and are not moved by STScI. **In attempting to match the U3 ORIENT (the value which goes into APT) of earlier data which was taken when no ORIENT was specified in the original program, one will need to find the PA_V3 angle in the data header for the original observations and then use the angle 180 degrees off from that in a 360-degree circle for the new U3 ORIENT angle in APT.** Also, in APT/Aladin, fairly shortly after the execution of a visit, once the visit status shows as "executed", the actual position and ORIENT angle on the sky **as executed** is shown in APT/Aladin for earlier observations and should confirm what is seen as the PA_V3 in the data headers for those executed observations, and therefore the U3 angle 180 degrees off from that which would be required to add in the new APT proposal in order to exactly repeat the earlier observations.

The use of specifying ORIENTs may also be important in observations such as polarimetry and in techniques such as using multiple roll angles (ORIENT angles) to disentangle PSF effects when searching for evidence of extrasolar planets around other stars. One may specify a single fixed ORIENT range with both ends the same, or it may be opened up some or even very widely if only wanting to exclude a very small ORIENT range. Multiple ORIENT ranges may also be defined which exclude regions where something bad or undesirable may happen (scattered light effects from stars, as above and elsewhere in this article), or where there are a number of alternative acceptable ORIENT ranges. Either way, the ORIENT ranges that are specified by the observer are the range(s) of ***acceptable*** ORIENTs. Please see more about the combined use of ORIENTs and apertures in the text in "Aperture Choice and using ORIENTs" in the Phase II portion of this document, particularly in the beginning of that section and in the parts dealing with the various ACS/WFC apertures.

Bright Object Checks for ACS/SBC Observations

For ACS/SBC observations, **proposers are required to make preliminary Bright Object Checks** to confirm that there are no bright object Health & Safety risks due to the target and field objects around it, and to **notify STScI** if such have been found. **Proposers are also required to develop and present a plan for how to address any bright object concerns** which are found, if possible, **and to present that information in the proposal.** Please see more details in the Phase I and Phase II documentation.

Special Calibrations

It should be remembered that not all modes and uses of science instruments are routinely calibrated by STScI. When proposing, it should be determined whether observations of the nature being proposed are routinely calibrated by STScI. In addition to unusual modes, etc., some highly demanding observations may require such things as contemporaneous PSF observations with specific placement on the detector at the same position as the science target. **If such demanding observations or other unusual modes which are not routinely calibrated by STScI are being proposed, it is the proposer's responsibility to investigate whether special calibrations will be needed and to propose for additional time/orbits needed to make any necessary special calibration observations.** If these are not included in the Phase I estimate, the proposal may be judged infeasible, or if somehow approved without the necessary calibrations, it may then exceed its TAC allocation when the necessary calibration observations are included and therefore require application to the TTRB for the extra needed time. Since it was the proposer's responsibility to highlight and request this time in Phase I, it may potentially not be granted by the TTRB, or the necessary time may have to come out of the science allocation to the detriment of the science observations or sample size, etc. See more details about this in the usual relevant Phase I documents.

Regarding PSF calibrations, some work has been done on providing PSFs for ACS, but it is the proposer's/observer's duty to determine if these will be sufficient for their science needs or if extra time for contemporary or more extensive observed PSFs may need to be included in a proposal's required orbit estimate for the necessary calibrations. In particular, see Bellini et al. 2018 (ACS ISR 2018-08), Hoffman and Anderson 2017 (ACS ISR 2017-08), as well as Anderson and King 2006 (ACS ISR 2006-01) and references within those ISRs for much of the more recent work on PSFs.

4. Phase II Program Development and Design Issues

This section documents some of the most common and more detailed issues which observers should consider in Phase II. Some were issues which nominally had to be addressed in Phase I, but sometimes arise for various reasons as new issues in Phase II, so are repeated here. Issues of concern in Phase II tend to be even more specific in detail than in Phase I, but may generally be divided into a number of broad categories. Among these are:

- **I -** aperture choice and using ORIENTs
- **II -** buffer dumps and buffer management in prime or parallel
- **III -** cosmic rays versus readnoise and breaking up exposure time into exposures of optimal length
- **IV -** CTE issues: Standard ACS pipeline pixel-based CTE mitigation and correction for extended or point sources; effects of use of the ACS postflash; postflash and ACS/WFC (when to use it and, more often, when not to use it); CTE aperture; CTE correction formula; another pixel-based CTE correction method
- **V -** optimal dithering (hot/bad pixels, bad columns, cosmic ray removal, improving resolution, covering the chip gap or not, effects of geometric distortion on larger dither patterns, etc.)
- **VI -** grism observing (use of aXe and aXeSIM or their successor to plan observations, choosing whether or not to use the AUTO mode which adds contemporary imaging of the grism field of view or turning off the AUTO mode and using sufficiently relevant pre-existing imaging instead, avoiding important parts of spectra spilling out of the field of view, use of multiple ORIENTs to help avoid or disentangle confusion in spectra)
- **VII -** reference frames, high-precision astrometry, and PSFs
- **VIII -** LOW SKY, SHADOW, sky background levels and the ACS ETC, and the effects of CTE in low-background images as well as the effect of flat fields in trying to dig for faint objects in the noise, Phase II context and relation to postflash in Phase II
- **IX -** Optional Parameters
- **X -** ramp filters; making sure targets are placed correctly in ramp filter apertures to get correct desired wavelengths, FOV vignetting, prism, and polarizers (making sure that apertures and polarization angles are chosen correctly)
- **XI -** SBC and bright object checking, time dependent sensitivity, red leak, previous 30% underestimate of throughput
- **XII -** SBC operating temperatures and optimal times and durations for SBC observing; SBC LOW-DARK aperture
- **XIII -** SBC additional concerns
- **XIV -** scattered light (ghosts, dragon's breath, chip gap glints, CCD column bleeding and directions, diffraction spike directions) and crosstalk

- **XV -** Special Requirements: visit-level and exposure-level
- **XVI -** visit size optimization (number of orbits per visit) and related issues such as dither pattern integrity, pointing and tracking issues, as well as (again) optimal SBC operating temperatures
- **XVII -** WFC subarrays (how they can help and how they can't).

I - Aperture Choice and Using ORIENTs

The combination of target coordinates, any ORIENTs required or the nominal ORIENT at which data is taken by default, plus the chosen reference aperture and any POS TARGs or dithers will define the pointings used in an observation. In general, since the use of ORIENTs tends to impinge upon the limited resource of scheduling flexibility, tying observations to a certain period of the year, their use is generally discouraged wherever possible by STScI. Even when ORIENTs are used, proposers/observers are encouraged to be as flexible as possible in the specifications of acceptable ORIENT ranges. However, there are definitely legitimate reasons and situations where the use of ORIENTs is not only advantageous, but also required to achieve the main purposes of the observations. For some purposes, allowable ORIENTs may even need to be at strict, small ranges and possibly include their orthogonal and opposite alternatives in order to cover a (mostly) similar footprint on the sky. (Again, recall that ACS is not a completely square footprint on the sky, but is rather a somewhat rhomboid shape.) Please see more about the typical use cases for ORIENTs and other issues relating to their use in the earlier section on "Timing and ORIENT Requirements" in the earlier section above on "Timing and ORIENT Requirements" in the Phase I portion of this ISR.

As mentioned above, please note that due to its off-axis nature and the exact placement of the cameras within HST, the field of view (FOV) of ACS cameras is not exactly square. The most appropriate choice of aperture will likely depend upon the science and the related operational requirements. By default, if there are no other modifications (no POS TARG or dither specifications, etc.), the target coordinates are placed at the reference aperture location on the detector as accurately as possible. (This is obviously much more demanding for solar system programs where much depends on the ephemerides of the object and of HST.) The "-FIX" apertures WFC-FIX, WFC1-FIX, WFC2-FIX, and SBC-FIX are defined as geometric constants within the relevant field of view for cases where the constancy of exactly repeating field coverage and a population of field objects with earlier or later observations done with the "-FIX" apertures may be more critical than an object whose coordinates are placed at the reference aperture location. The other apertures such as WFC, WFC1, WFC2, and SBC may be moved slightly by STScI over time due to things like new detector defects near the defined aperture. However, any such moves are usually very small. Remember that it is a "best practice" to always view the layout of the FOV footprint(s) in APT/Aladin to confirm that they are as desired and behave as expected, and especially so if trying to repeat an earlier observation exactly. **To exactly duplicate an earlier observation, usually the exact same aperture and ORIENT angle should be used as was used in the original, although one must also always be mindful that, unless the original aperture was a "-FIX" aperture, it is possible that STScI may have moved the reference aperture position a bit over time for cosmetic reasons to avoid bad pixels or other chip defects which may have appeared over time.** Note that, in addition to the usual defects such as bad columns and charge traps and hot pixels, all full-frame ACS/WFC exposures (and some subarray exposures) will also contain some small anomalous image artifacts known as "flecks" which appeared on May 5th, 2017. These are not expected to have any appreciable impact on the science use of the ACS/WFC, but it is important to note and be aware of their their presence. ACS/WFC images are continually monitored to note the presence of any new flecks should any appear in the future. The issue of these flecks is documented in Hoffman et al. 2018 (ACS ISR 2018-03).

A more specific discussion of various apertures follows. **These are the apertures which are allowed in the GO Phase II Proposal Instructions aperture list and which are therefore more commonly used. There are other additional ones (some extra subarrays and an extra ramp filter aperture) in the Engineering Phase II Proposal Instructions which are only very rarely used, and which are available but unsupported in terms of calibration.** *Note also that, since it has no longer been working since January 2007, the ACS/HRC apertures including the HRC coronagraphic aperture are not discussed further here, but for the purposes of understanding unique earlier HRC and coronagraphic data in the context of proposing for new related observations, the location of it can still be seen in the HRC footprint in APT/Aladin if the "FOV" button to see all apertures is turned on, and one may read more about it in several early ACS ISRs, among them Krist 2000 (ACS ISR 2000-04), Krist 2002 (ACS ISR 2002-11), Krist et al. 2004 (ACS ISR 2004-16), and Cox and Biretta 2005 (ACS ISR 2005-05).*

- **WFCENTER** - Geometric center of the non-square, rhomboid-shaped ACS/WFC FOV. Best to use this if there is NOT a single small target at the area of the target coordinates but if instead seeking to maximize a combination of greatest scheduling flexibility and coverage of as many of the same exact full population of objects (e.g. stars or galaxies in clusters or in the field in the FOV) around a point or area of sky as possible, either across the full FOV at orthogonal and/or opposite ORIENT angles, or within the "central radius" area which is covered at any ORIENT angle, or as in any earlier observations which used WFCENTER. The use of WFCENTER makes it much easier to cover most of the exact same area on the sky at opposite and orthogonal ORIENTs or within an exact central radius from the field center coordinates by simply spinning around the center of the FOV. This is particularly good for programs which are doing mosaics of extended multiple contiguous tiles on the sky or for spinning a single FOV tile around one fixed central point when NOT placing a particular object of interest (or any object) there at the WFCENTER aperture coordinates. It is also good if trying to exactly repeat a prior observation which used WFCENTER and the exact same target coordinates and ORIENT. It is best thought of as a generic "central-spin" location for the ACS/WFC field of view since the target coordinates may esentially be very close to or on the chip gap, but the field of view will spin equally around this central point. If, however, there is a particular object of interest which is desired to image well such as a brightest cluster galaxy, for example, if it is still desired to allow the field of view to spin around that object somewhere fairly close to the center of the field of view even though still offset somewhat and therefore with the FOV spinning a bit off-center, consider using the WFC aperture below instead.

- **WFC** - Current "optimum" clean aperture location for small angular size target of particular interest at target coordinates position which will be placed on WFC1 and near but not in the chip gap and slightly off from the center of the full FOV. Generally suffices for full-FOV coverage but spinning somewhat off-center through the full ORIENT range. It is good for possibly exact – if reference aperture position has not been moved by STScI over time - or near repeat of earlier observations using the WFC aperture at the SAME ORIENT but if still very interested in the environment across the entire 2-chip FOV. (If using this aperture and observing at orthogonal or opposite ORIENT angle with respect to earlier observations, then it will be somewhat off-center from the earlier observations.) Reference aperture location may move slightly over time if needed to counteract development of bad or hot pixels at the reference location. Rotation of the FOV around the aperture will be somewhat off-center.
- **WFC-FIX** – Same as WFC aperture except temporally invariant, geometrically-fixed reference aperture. However, since reference aperture is never moved, over time it may suffer from reference aperture location and other nearby areas becoming non-optimal due to development of bad/hot pixels, etc.
- **WFC1** - Best if target area of concern is contained within minimum radius of one chip (WFC1) and only doing very small dithers, i.e. not chip gap dithers. Optimal aperture reference location may be moved slightly from time to time but always near the center of the chip.
- **WFC1-FIX** – Same as WFC1 aperture except temporally invariant, geometrically-fixed aperture located at the center of the chip. Nominally acceptable for exact repeats at exact same position and ORIENT over time for populations of objects across the FOV since reference aperture position does not move over time. However, detector pixels at actual reference aperture location

may become non-optimal over time.

- **WFC2** - Best if target area of concern is contained within minimum radius of one chip (WFC2) and only doing very small dithers, i.e. not chip gap dithers. Optimal aperture reference location may be moved slightly from time to time but always near the center of the chip.
- **WFC2-FIX** – Same as WFC2 aperture except temporally invariant, geometrically-fixed aperture located at the center of the chip. Nominally acceptable for exact repeats at exact same position and ORIENT over time for populations of objects across the FOV since reference aperture position does not move over time. However, detector pixels at actual reference aperture location may become non-optimal over time.
- **WFC1-CTE** – As the ACS/WFC CCDs age, the effects of CTE become worse. If there are very stringent requirements for a target that is very small in angular size and perhaps faint at levels where the CTE effects are worst and it is desired not simply to rely on the standard pipeline CTE correction but also to minimize the initial charge losses and displacements due to CTE effects, this aperture may be preferred. Note, however, that it truly is for targets of very small angular size as it is very close to the edge of the chip because it is designed to be very close to the Amp B location, which is the most-frequently used Amp for this task. If it is also desired to image some larger area of the environment around the target object, this aperture may NOT be suitable choice. Be sure to look at the FOV layout in APT/Aladin to verify that the use of this aperture location is acceptable for the science goals.
- **Subarray apertures** – The overall 2-chip ACS/WFC FOV is comprised of 4 amplifier quadrants, with 2 being on each chip. There are various subarray apertures of different sizes with reference aperture locations on the different quadrants on each chip for use with the different amps on each chip. Reasons for using the different subarrays may include such things as instances where ACS/WFC is being used in parallel and it is advantageous in terms of buffer management not to have to store data from the full detector FOV, and targets of specific location and size may fall onto the area of one amp quadrant or another, or the size, shape, and location of the target may dictate which of the various subarrays need to be used. If the smaller FOV of a subarray can be used, more of them can be stored in the ACS internal memory buffer before needing to be read out, therefore some overhead time for buffer dumps may potentially be saved. Amplifier B has been the most steady over time, and is often the one most used. However, in addition to the redundancy they provide, there can be uses for the others in various situations as noted above. Please see the full list of subarray apertures and descriptions of them and more about overheads in Chapters 7 and 8

respectively of the ACS Instrument Handbook.

- **Ramp Filter apertures** – There are various ramp filter apertures of different sizes with reference apertures located on one or the other of the WFC chips. Please note that the location of reference apertures of the ramp filters is wavelength dependent, with the targeted central wavelength value varying across the filter, so the choice of desired central wavelength will have an impact on the positioning of the target coordinates within the FOV. Please also note that the FOV is subject to vignetting when using ramp filters. It is incumbent on the user to look at the apertures as represented in APT/Aladin to see where any part of the FOV may be vignetted, and where the target coordinates will be placed for the given central wavelength. Please see the full list of ramp filter apertures and descriptions of them in Chapter 7 of the ACS Instrument Handbook.
- **SBC** – Reference aperture location near but not at the center of the ACS/SBC field of view. It is also not located on the repeller wire, a wire in the field of view which obscures several columns of the SBC detector and is always on for SBC observations, increasing the Quantum Efficiency of the detector. (See Chapter 5 of the ACS Instrument Handbook, and Figure 2 of Cox, C. 2005, "The HST 2005 Calibration Workshop".) The generic SBC aperture may move over time if necessary due to bad pixels, etc.
- **SBC-FIX** – Temporally-invariant, fixed reference aperture location near but not at the center of the ACS/SBC. It is also not located on the repeller wire.
- **SBC-PRISM** – Not available as a user choice in APT, this aperture is automatically created by the commanding software when spectral elements PR110L and PR130L and aperture SBC are selected in APT. There is some vignetting on the positive-x (right hand side) of the field, but targets are automatically positioned for optimal observing. See Chapter 7 of the ACS Instrument Handbook for more. Note that the SAME POS AS reqirement cannot be used on SBC imaging mixing the use of both direct SBC and PRISM images since HST automatically moves a tiny bit between these two kinds of images.
- **SBC-LODARK** – After about 2 hours of the SBC being turned on, it reaches a temperature at which the dark rate becomes elevated over the FOV of most of the detector. However, there is a corner of the SBC detector where the dark rate remains constant at all temperatures. The use of this aperture places the target coordinates at a location in this corner of the SBC detector. This is especially useful if the principal target at those coordinates is of small enough angular size to fit within the low noise region and if the SBC has to be turned on for a longer time for observational purposes, etc. Generally, any user who needs to observe continuously for longer than ~2 contiguous orbits at a time should consider using this aperture if the target area of interest is small enough to fit within the SBC-LODARK aperture area. There is a small cluster of (currently 4) bad pixels which

always have elevated counts which are inside the SBC-LODARK aperture and which are marked as bad in the data quality arrays, and users should discard those in processing. See R. Avila et al. 2018 (ACS ISR 2018-07) and references therein for more about SBC-LODARK, operating times, dark count rates, and heating and cool-down behavior of the ACS/SBC detector.

Please see the ACS section of the Phase II Proposal Instructions and the ACS Instrument Handbook for more details on each of the apertures above, and for allowed combinations of apertures, filters, ramp filters, polarizers, and prism, etc. There are also additional subarray and ramp apertures which are available but unsupported. Please see the Engineering Phase II Proposal Instructions for more on these additional apertures if needed. They should only be used in very rare circumstances.

For all uses of any aperture, it is highly recommended to bring up the observations in APT/Aladin and look at what has actually been specified to make sure that the target position is being placed in an area where it is expected to be. If trying to repeat or match earlier observations with the same detector, look at the program specificationa for the earlier observations. Is the new aperture choice the same? Even with that, could its position have changed over time? Were there any manual offsets applied via POS TARGs or some particular dithering pattern, especially if a large one? Was there an ORIENT or ORIENT range specified for the earlier observations? Even if no ORIENT or an ORIENT range was specified with a given aperture for the earlier observations, to match them, one will need to use a specific ORIENT range with both ends having the same value and will also need to make sure that the aperture is the same and is not one that could have changed location appreciably over time. For ramps and subarrays, note especially that many RAMP apertures are vignetted, and for subarrays, only data from the relevant parts of the detector are stored. See the next section on buffer management for more on these matters related to subarrays. And, as always, one may ask the assigned Program Coordinator or Contact Scientist (if one has been assigned to the approved program) or the instrument group via the Help Desk for more help if uncertain about something.

II - Buffer Management

The advantages of wise buffer management and savings on overhead times with ACS are mostly found in the dimension of buffer space and data storage and the need of possibly doing fewer buffer dumps overall. If data from the wider field around a small target of interest is not needed, it is possible to fit a larger number of smaller subarray images into the buffer and have them dumped all at once, together. The overhead time required for dumping the buffer contents to the ground is still about the same no matter the number of subarray images. So, it may be possible to take a larger number of subarray images per orbit, and have a larger number in one filter, or take more images using a number of filters in order to take the best advantage of the way buffer dumps work. The big advantage is in being able to fit a larger number of smaller subarray images than full-frame images within a given buffer dump if only the area around the target within the FOV of the chosen subarray is of concern. If taking full-frame images instead, more buffer dumps would be needed, and therefore the overhead time would add up quickly for each of those.

Parallel observations in multiple instruments, whether full-frame or subarrays, will also constrain the buffer dumps to the ground more, and so, if not wanting to waste time dumping the buffers during possible unocculted science observation time for the target (i.e. when Earth is not blocking the view of the target), the best strategy is usually to try to force buffer dumps to take place during the target occultation if possible, at the end of the target's orbital visibility period for each orbit. However, this may not always be possible, and buffer management is an important factor in maximizing science time on target. If taking very long exposures, there will, of course, be less need for more frequent buffer dumps, and lower read noise per exposure, but this is usually more than countered by the fact that there will be many more cosmic rays per exposure, and there will be fewer images, and so the cosmic ray rejection and dithering strategy will be correspondingly less robust and subject to more noise of that sort. Therefore, once again, it is a trade-off, and it is generally better to have a larger number of dither positions and more robust cosmic ray rejection where possible.

Of course, the best way to understand how buffer management will actually work for any particular observing strategy and set-up is to design and test a Phase II-style mock-up in APT. If it works in APT, it should work on the telescope, and it can give a better feel for how the various options will actually play out, and will usually show any limitations or fortuitous benefits.

III - Cosmic Rays versus Readnoise: Optimizing Times per Exposure

As noted in the section on buffer management above, longer exposures may typically benefit from having lower readnoise, but this is counterbalanced by the fact that longer exposures will also likely be fewer in number and have many more cosmic rays per exposure. With fewer exposures and more cosmic rays per exposure, the cosmic ray rejection will be less robust, and the effectiveness of having more dither positions for better cosmic ray rejection, better minimization of the effects of hot or bad pixels, bad columns, and various chip or detector defects is reduced. The improvement of resolution from sub-pixel dithering is also negated. As is often the case, there is a trade-off to be considered. One can try and make some estimates of this using the ACS Exposure Time Calculator (ETC), but our general advice is that more dither positions and more exposures is generally a better strategy to follow. Many prominent extragalactic survey programs have commonly used a strategy of filling orbits with more dithered exposures all in the 500 second to 1200 second range, with all exposures of a given filter typically having a similar exposure time for better, more robust image combinations when all are being drizzled together into a final image for that filter. (The drizzling software does not require all exposures to have the same exposure time in order to work or be effective, but if the exposure times are drastically different with drastically different signal-to-noise and noise levels, the results will be noisier and not as good as for exposures with similar exposure times and signal-to-noise levels. Remember, however, that the relationship between exposure time and signal-to-noise is not linear, but signal-to-noise instead goes as the square root of the total exposure time. Similarly, binning the data when taking it can increase the S/N, but of course at the cost of losing some of the native resolution when binning, and higher resolution is of course one of the chief advantages of using HST and ACS. See the link to the DrizzlePac documentation in the “Other Resources” section at the end of this ISR for more on the workings of the DrizzlePac software, including AstroDrizzle.) Please note that the default value for the exposure-level optional parameter CR-SPLIT is NO, e.g. CR-SPLIT=NO, and this is in good accordance with the typical best practice of dithering between all exposures.

The number of hot pixels grows with time due to radiation damage, so data taken in later times will inherently be noisier. However this can be mitigated when taking multiple dithered images and then combining them. With more dithered images, there is a greater chance that there will be more good data in the stack of pixels at some given position on the sky. Therefore, as radiation damage advances with the age of the instrument, more pixels are thrown out as hot pixels, and more images and more dither positions are required to beat down the noise. However, note that improvements have also been made in understanding and tracking pixel histories of so-called hot pixels, etc., some of which are not always bad. Pixel histories for the ACS/WFC have been studied and some pixels previously thought to be bad are brought back into science images as reliable pixels, thus “saving the pixels”, or at least some of them. See Borncamp et al. 2017 (ACS ISR 2017-05) for more on this. The read noise history of the ACS/WFC amplifiers has also been studied and their relative performance compared in Desjardins 2019 (ACS ISR 2019-02 and references therein) which also may have some bearing on choice of, for example, subarray, when subarrays are being used. In general, using the ACS ETC to estimate quantities such as maximum acceptable read noise level per exposure and determining how many exposures of a target this will allow within a desired given total exposure time required to reach the ultimate intended signal-to-noise will help the proposer or observer get an idea of the number of dithered exposures which would be desirable. From that, factoring in the related overheads such as buffer dumps will help determine how many dithered exposures are actually possible within a given number of orbits.

IV - CTE Issues: Standard ACS pipeline pixel-based CTE mitigation and correction for extended and point sources; Effects of ACS Postflash; Postflash: When to use it, and (more often) when NOT to use it; CTE aperture; CTE correction formula;

Another pixel-based CTE correction method

CTE effects on CCD detectors like ACS/WFC are minimized nearest the amplifier through which the charge is read out and become progressively worse further down the detector columns from the amplifier. ACS/WFC has 4 amplifiers in its 4 outer corners, one for each half of the 2 CCD chips. The effects of CTE are the greatest and most deleterious for the faintest objects. CTE affects not only the photometry of objects, but also the astrometry. The effect is particularly more pronounced and of a larger magnitude down detector columns in the detector y-direction (the same axis as the detector column readout direction), but much smaller, less significant but still sometimes-noticeable effects (though currently less-well characterized) are also sometimes seen along rows in the detector x-direction. Standard data pipeline corrections have been put in place by STScI to move the signal back to where it most properly belongs, producing the *_flc.fits files which have been CTE-corrected, as opposed to the *_flt.fits files which have not. In general, these corrections do a very good job, especially for brighter sources, and down to a fairly faint level. However, as it nears the faintest limits, this begins to become somewhat less reliable.

The standard pipeline corrections are perhaps easier to verify for stellar point sources, but they also seem to be very good for extended sources as well, except perhaps at the very faintest levels. Self-shielding also helps to reduce the effect in extended sources. Extended sources suffer significantly less charge-trailing during readout because of "self-shielding": the electrons from the leading edge of the extended source more effectively fill the CCD charge-traps responsible for poor CTE so that the upstream pixels effectively have higher sky background and suffer less from CTE.

Unlike the WFC3/UVIS postflash described in Biretta and Baggett 2013 (WFC3 ISR 2013-12) and Medina et al. 2019 (WFC3 ISR 2019-10), the ACS/WFC postflash is highly non-uniform, varying by a factor of 2 over the radius from its highest level in the center of the ACS/WFC field of view to its lowest, weakest level in the outskirts of the field of view (Ogaz et al. 2014, ACS ISR 2014-01; Miles et al. 2018, ACS ISR 2018-02). The ACS ETC currently issues warnings and advises the possible use of the postflash for exposures where backgrounds are projected to be less than 20 electrons, often in the case of broadband exposures of less than 300 seconds or so, or in longer exposures with narrow- and medium-band filters. In practice, unless the scientific goal is purely one of mere detection only, or of photometry of some source of small angular size placed in the center of the ACS/WFC field of view, for most typical uses where the observer wishes to have readily interpreted relative photometry across the entire FOV, and/or where a comparison to similar data on the same target field taken at other epochs or even images of other similar targets, the use of the ACS/WFC postflash is generally NOT presently recommended as of Cycle 26, in 2019/2020. Exceptions may be in some cases where there are photon-starved narrow- or medium-band exposures or very short broadband exposures. However, its use will greatly complicate any observations where relative or absolute photometry is important, and whether comparing to other data on the target in the same or other filters over the field of view, or comparing to historical data from ACS/WFC or any other telescope and/or detector in any wavelengths, use of the ACS postflash will likely just complicate the analysis to a degree that makes it too difficult a task for most purposes. The primary reason for using the ACS/WFC postflash at present would be for mere detection of the faintest objects over the field of view or at the center of the field of view, with little or no regard for even the relative photometry of sources across the field of view. Please see Ogaz et al. 2014 (ACS ISR 2014-01) and Miles et al. (ACS ISR 2018-02) and references therein for more on ACS postflash.

In subsection **viii** farther below, the interplay of CTE effects and the use of LOW SKY or SHADOW requirements is also discussed since these requirements are designed to minimize sky background from scattered light, but low backgrounds and faint magnitudes are also where some of the most insidious and unrecoverable effects of CTE occur, and again, it is often a trade-off when determining which factors are most critical for a given situation or scientific purpose.

As mentioned farther above in the "Apertures" section, there is a special aperture called WFC1-CTE which uses the amp which has been most steady and reliable over time, Amp B of ACS/WFC, at a location very near that amp. Use of this aperture, even before the CTE corrections are applied in the ACS data pipeline, will help to minimize the effect. However, the aperture location, to be at its most effective, is very near the amp and therefore very near the edge of the detector's field of view, and is therefore mainly good for objects of nearly point-like nature and very small angular size. If the proposer/observer is also very concerned about the environment for some wider area surrounding the target source, this aperture may not be the best choice. As always, it is best to look at such options using the APT/Aladin display feature overlaid on the Digitized Sky Survey images or similar astronomical images which have been WCS-transformed to the Guide Star reference frame which will be used for the HST observations.

In summary, the pixel-based CTE correction which now happens automatically in the standard ACS calibration pipeline does a very good job of eliminating the CTE tails down CCD columns and putting the charge back where it belongs, both in terms of photometry as well as astrometry, especially for the brighter sources, though it is less effective at the faintest magnitudes where the effects of CTE are the worst and most insidious. One can readily see the improvement visually when looking at an uncorrected ACS/WFC *.flt image versus a CTE-corrected *.flc image. This automatic pixel-based CTE correction also improves the astrometry as well as the photometry and morphology of objects, as all of these qualities are affected by CTE when the charge is trailing down the column rather than remaining where it is supposed to be and where it is on the sky.

There is also a CTE photometric correction formula which is best and most effective when applied to stellar objects of sufficient brightness. See ACS ISRs 2009-01

(Chiaberge et al. 2009) and 2012-05 (Chiaberge 2012) for more on the CTE correction formula.

See also ACS ISRs 2018-09 (Ryon and Grogin 2018), 2018-04 (Anderson and Ryon 2018), 2018-02 (Miles et al. 2018) and references within those ISRs for more on characterizing and mitigating CTE via pixel-based correction in ACS/WFC. An alternate pixel-based approach and related effects on galaxy morphologies has also been discussed and published by Massey et al. (2010a, 2010b) and Rhodes (2010).

V - Dither Optimization: Addressing Hot/Bad Pixels, Bad Columns; CosmicRay Removal; Improving Resolution; Chip Gap Dithers; Effects of Geometric Distortion on Larger Patterns

Dithering, small movements of the telescope which place the target and field of view on slightly different parts of the detector, shifting slightly from exposure to exposure, improves the quality of ACS data in a number of different ways. Whenever possible, ACS imaging should involve dithering. A bare minimum of 2 dither positions should always be used if possible, but it is usually much better if there are at least 3 or 4 or more dither positions if there is also time for individual exposures of reasonable length to minimize read noise. Pre-defined, standard dither patterns such as diagonal line dithers of 2 or more points and standard box dithers of 4 points as well as hybrid dither patterns utilizing a combination of these all exist. (See more on this below.)

The reasons for dithering and the benefits it provides are many. Whether transient or permanent effects, detector anomalies such as hot pixels or otherwise bad pixels and/or bad columns, charge traps, as well as the effects of cosmic ray hits are all best addressed by dithering. In addition to that, some larger dithers may cover the ACS/WFC chip gap (a gap of 2.5 arcseconds or 50 ACS/WFC pixels) if that is important for the science. (If that is the case, it is also usually best to have at least two images or preferably 3 everywhere in the chip gap for robust cosmic ray removal there, if possible. Also, if chip gap or larger dithers are used, it should be noted that the effects of geometric distortion across the field of view affect the integrity of the dither patterns to a greater degree at points farther from the aperture of reference. See more about this including links to a plot from the ACS dither pages mentioned below.) Last but certainly not least, the resolution of the final drizzle-combined data may be improved over that of the native resolution of the detector by subsampled dithering where successive images are dithered by non-integer pixels. If doing non-integer pixel shifts to improve the resolution of the final combined image, **1/2-pixel shifts tend to show the most notable improvement**, but if one has the luxury of having time to take many images, shifts of ~1//3 pixel in addition to the images using 1/2-pixel shifts may add a bit more to the refinement of the increased resolution. If doing small, non-integer pixel dithers, **a minimum shift of something like at least 5.5 x 6.5 or 6.5 x 7.5 pixels should be used** to be sure to avoid any problems with spill-over from any bad columns or blobs. **However, if calculating such offsets manually, it should be remembered that the shift values given in both dither pattern specifications and manual POS TARG specifications are in units of arc seconds, not fractional pixels.**

Note that, in addition to the standard “dither line” (of 2 or 2+n points) and “dither box" dither patterns, it is possible to define both primary and secondary dither patterns. In this way, one may create hybrid dither patterns which can both bridge the chip gap with multiple images for reasonable cosmic ray rejection in the gap, and provide multiple images with, for example, small non-integer pixel offsets for enhancing resolution and dealing with bad or hot pixels, bad columns, other chip defects. There are some pre-defined ACS dither patterns in the Phase II Proposal Instructions, and links within that to another ACS dither page that has links to multiple dither pages with a pre-defined set of line and box dithers. In addition to that, other information and examples which can help in the design of hybrid dither patterns or dither patterns with various different strengths can be found there. Also available there are examples of POS TARG equivalents and how to calculate them if one wishes to manually define the dithers by use of POS TARG commands. The use of POS TARG commands as opposed to canned dither patterns can sometimes be especially useful for specific purposes in certain situations for some programs.

Section 7.2 of the HST Phase II Proposal Instructions at https://hst-docs.stsci.edu/display/HPIOM/7.2+ACS+Patterns has more information, as does the ACS dither strategies page at http://www.stsci.edu/hst/instrumentation/acs/proposing/dither-strategies as well. Please see the aforementioned web pages for more information and various canned dither routines which may be utilized either alone or in hybrid combinations to best address the requirements of each type of observation.

VI - Grism Observing: Using [aXe](aXe) to Plan Observations; Keeping Spectra on the Detector; Minimizing Spectral Confusion by Using Multiple ORIENTs; aXe replacement

Observing with the ACS/WFC grism brings with it a number of unique challenges. First and foremost, there are the issues of source identification and source confusion. There is also the issue of identifying the different orders of spectra and keeping the desired spectra on the detector rather than spilling over the edge and falling off of it. In the current ACS grism software, aXe, there is a planning and simulation tool called aXeSIM which helps one try to understand and visualize these issues. Sometimes, one solution to help mimimize source confusion is to roll the telescope between different grism exposures so that the spectra of some objects which may have fallen on top of others may now fall in a different place in the image, perhaps onto the spectra of other different objects or in blank spaces between objects. Also note that, by default, a direct image is taken along with each set of grism observations in order to help confirm the exact pointing of the spectroscopic observations and the locations of sources in them in order to help reduce source confusion, but this can in some cases be turned off in APT if very good prior imaging of a field is already in hand. Note that aXe currently relies on IRAF/STSDAS, but is being re-written in Python. Initial on-orbit calibrations of the G800L grism with both WFC and HRC were done by Pasquali et al. (2003a and 2003b) in ACS ISRs 2003-01 and 2003-07.

(Information about HRC is only included here in case it is of use in assessing old HRC data for potential newer G800L observations with the WFC.) Other earlier calibrations included flat-field and sensitivity of the ACS G800L which was documented in Walsh and Pirzkal 2005 (ACS ISR 2005-02) and references within that ISR, and an updated wavelength calibration for the WFC/G800L grism by Larsen and Walsh 2005 (ACS ISR 2005-08). Please see Hathi et al. 2019 (ACS ISR 2019-01) and references therein for more recent details on long-term stability and other related issues regarding the ACS/WFC G800L grism.

VII - Reference Frames, High-Precision Astrometry, and Point Spread Functions (PSFs)

Accurate astrometry may be considered in both an absolute and relative sense, and may be considered over a wider area as well as over a much smaller, confined area. For larger-scale, absolute accuracy, it may be desirable to tie data to high-quality astrometric catalogs such as that from Gaia. Bajaj (2017) has shown such a method for the WFC3 cameras which is equally applicable to ACS data. Having accurately-aligned imaging can be very important for other later applications such as creating image mosaics or planning high-precision multi-object spectroscopic follow-up with small apertures or optical fibers, for example.

On smaller scales, scientific goals requiring very high-precision astrometry must also account for the fact that ACS has geometric distortion across its field of view due to its off-axis location in the HST focal plane. There is also a smaller time-dependent element to the geometric distortion due to inherent artifacts of the CCD manufacturing process and effects due to on-orbit aging and slight movements over time, but this has largely been very well corrected for via distortion calibration files both internally and with respect to various external catalogs. For more on these topics, please see Kozhurina-Platais et al. 2018 (ACS ISR 2018-01) and Kozhurina-Platais et al. 2015 (ACS ISR 2015-06) and references therein.

Some users such as those observing structures around bright AGN nuclei or extrasolar planets may have very stringent requirements relating to high-fidelity point spread functions (PSFs) of point-like sources. HST imaging including that with ACS is affected by a number of factors including spatial geometric distortions over the field of view of the detectors as well as short-term temporal variations known as “breathing” which is related to temperature variations on the bright and dark sides of HST’s orbit around the Earth. In earlier times, TINY TIM software (Krist et al., 2011) was often used for much PSF work, but more recent work has since proceeded on a PSF library (Anderson and King, 2006) and related models as compared to Tiny Tim (Hoffman and Anderson, 2017) as well as focus-diverse, empirical PSF models using the Anderson and King PSF library as input (Bellini et al., 2018). Please see those publications and the listed resources and other references within those documents for more on PSFs.

Note also that uncorrected or improperly-corrected CTE effects can also affect astrometry as well as photometry and can be important where the greatest astrometric accuracy and precision is concerned.

VIII - LOW SKY, SHADOW; sky background levels and the ACS ETC; Flat Fields; relation of these to ACS/WFC postflash in the Phase II Context

The exact nature of the proposed science may argue for either lower or higher sky backgrounds. **The minimization of sky background levels due to scattered light is especially important for the study of fainter, extended objects, and any need for the use of LOW SKY or SHADOW requirements must be addressed and documented in Phase I proposals due to their being a limited resource which impacts scheduling.** The issue is ultimately also related to flat fields and the levels to which one can dig into the noise in the data to meet the scientific goals of the proposal. Some scientific goals may demand a very low sky background in order to make out such things as the detailed morphology of faint galaxies, and the achievement of these goals may be adversely affected by unusually high sky backgrounds from things like scattered Earthshine or background zodiacal light at certain times of year. Use of the ACS ETC can help determine when this may be a concern. In the ACS ETC, one can enter a source's position etc. to see if this is a concern one may need to address by the use of a LOW SKY or SHADOW requirement.

In terms of ACS background light versus Bright Earth Limb Angle, there has also been a study on this subject published in Biretta 2003 (ACS ISR 2003-05).

Note, however, that although some CTE effects such as charge trailing down columns are more prominent for bright objects such as stars, other CTE effects such as unrecoverable loss of charge are also worse and more insidious for faint, extended objects when the sky background levels are very low and the goal is mere detectability. There may be more rare circumstances where the ACS/WFC postflash (NOT currently required to be specified in Phase I) is needed, primarily where the goal is not so much accurate photometry, but simply the mere detection of very faint objects, even though the detection of faint objects near the center of the ACS/WFC field of view will be much more enhanced than that of objects nearer the edges, given the large non-uniformity of the ACS/WFC postflash across the field of view, unlike that of the WFC3/UVIS which is much more uniform. See Biretta and Baggett 2013 (WFC3 ISR 2013-12) and Medina et al. 2019 (WFC3 ISR 2019-10) for more on the WFC3 postflash, and Ogaz et al. (ACS ISR 2014-01) and (Miles et al. 2018, ACS ISR 2018-02) for more details on the ACS postflash.

Ideally, it is desirable not to have scattered light like Earthshine or zodiacal light be too high so as to adversely affect such things as detectability and measurement of faint objects and measurement of their morphologies, but at the same time it is also

desirable to have a high enough sky background level to be able to avoid losing those same faintest objects to the unrecoverable effects of CTE losses which is more prominent for objects at the fainter end. Generally speaking, a level of 20 electrons is currently considered to be a good minimum background level. However, depending on the scientific goals of the observations, this is sometimes something that has to be ignored and lower background levels accepted. This is especially true in cases where one is concerned about good relative or absolute photometry for objects across the ACS/WFC field of view and not just the pure detection of objects. This is because of the highly variable effectiveness and level of the ACS/WFC postflash which falls off by a factor of 2 from the center of the FOV to the edges of the detectors. See more about the ACS postflash in the discussion of CTE effects in subsection **iv** above.

If trying to dig deep into the noise to detect and identify faint objects, the nature of the flat fields may be important to consider. Please see Bohlin and Grogin 2015 (ACS ISR 2015-07) and Mack et al. 2017 (ACS ISR 2017-09) and references therein for more on ACS/WFC flat fields and sky flats.

IX - Optional Parameters

The most common Optional Parameters are CR-SPLIT, GAIN, AUTOIMAGE, and FLASH. The default for CR-SPLIT is CR-SPLIT=NO since most sequences of exposures are now dithered. Almost all ACS/WFC observations are now taken with the default GAIN = 2 setting. Images are automatically taken in some modes such as grism observations, but in special cases where autoimages are unnecessary such as when sufficient imaging of a grism target field already exists, the AUTOIMAGE optional parameter may be turned off. The FLASH Optional Parameter is used to control the amount of postflash to be added to exposures in the fairly rare cases where the use of it is recommended. (See more about FLASH and the relation to CTE effects in subsection **iv** above.) Some other Optional Parameters may be restricted in their usage and only normally available for use in engineering and special calibration proposals. Please see the Phase II Proposal Instructions for more details. The GO sections (text in black) have the parameters most frequently needed or used, while the parameters for capabilities considered “Available but Unsupported” (use requires prior approval from STScI, text in magenta), “Restricted” (STScI-use only, text in red), and “Engineering” (use requires prior approval from STScI, text in green) of the Phase II Proposal Instructions also have more information on the more unusual ones which are usually limited-use and usually require extra justification and special requests to use.

X - Ramp Filters; Prism; Polarizers

Ramp Filters are selected by the chosen wavelength, and the position of the target on the detector and within the ACS/WFC field of view is dependent on this wavelength. Note that the field of view of some ramp filters is vignetted. As with other observations, it is an important part of proposal planning to bring up APT Aladin and see how the field of view will look and be affected for the specific observations. Targets may vary in size and geometrical shape on the sky, and the wavelength regions of interest are generally covering an area of fairly small angular size on the sky.

The ACS/HRC and SBC both had prisms, but only the SBC remains active now. If intending to use the SBC prisms, please read more about them in the latest ACS Instrument Handbook and Phase II Proposal Instructions.

Both HRC and WFC had polarizers, but only the WFC is currently active since HST SM4 in 2009, after the earlier ACS shutdown in early 2007. Stars as well as an extended source (the Boomerang Nebula, Visits 01-04 of HST Program 10378 for the ACS/WFC portion) were imaged with both HRC and WFC, and have been used for calibration and to check the variation in Stokes parameters with HST roll angle, and to look for evidence of phase retardance effects. This historical information may be useful to know if taking earlier polarimetric observations of a target into account when proposing new observations of any type. For the latest information on the ACS Ramp Filters, Prisms, and Polarizer, check the ACS Instrument Handbook and Phase II Proposal Instructions and any ISRs on the subject.

Initial throughput and bandpass measurements of the ramp filters were documented in Bohlin and Tsvetanov 2000 (ACS ISR 2000-05) and flat fields for the ramp filters were documented in Bohlin and Hartig 2002 (ACS ISR 2002-01). For more on the ACS/SBC PR110L and PR130L prisms, please see Larsen 2006a (ACS ISR 2006-02) and, though the ACS/HRC is no longer working, if information is needed for planning observations at other wavelengths but relying in part on ACS/HRC PR200L prism data, please see Larsen et al. 2006b (ACS ISR 2006-03). Initial pre-flight polarization properties of ACS were measured and published in Walsh 2001 (ACS ISR 20001-01). For more on ACS Polarization, see Cracraft and Sparks 2007 (ACS ISR 2007-10) and references therein, as well as a series of ISRs (Parts I-IV) by Biretta et al. (2004a) and by Biretta and Kozhurina-Platais (2004b), Kozhurina-Platais and Biretta (2004), and Kozhurina-Platais and Biretta (2005). Although the latter two ISRs are solely concerned with the now defunct ACS/HRC, mention of them is included here in case they are of any importance to GOs in understanding data from any earlier observations when planning new and different proposals and/or observations. New work on furthering ACS polarization calibration is underway at the time of this writing (December 2019), but is not yet ready for publication.

XI - SBC and Bright Object Checking: Time-Dependent Sensitivity; Red Leak; Long-Term Error in SBC Throughput and in Published Magnitudes

The SBC detector is a MAMA detector which may be damaged by sources that are too bright or exceed a certain count rate within a given time. Though the STScI staff perform a safety check of such observations, proposers/observers who are using the ACS/SBC are initially required to do Bright Object Protection (BOP) checking themselves and to provide summaries and ACS ETC run numbers to STScI detailing their calculations. In some cases, data from other telescopes, especially UV data from telescopes such as GALEX, IUE, and/or other space-based UV telescopes, may be necessary to clear certain objects whether they are the targets themselves or other objects in the potential field of view of the observations which may be covered by the detector over the full ORIENT range. There are further instructions on this in the various proposal preparation documents and in the APT BOT (Bright Object Tool) itself. Although somewhat older, and proposers/observers should be sure to follow the latest instructions and procedures involving use of the APT BOT, there is also an older ACS ISR on policy and procedure for MAMA targets subject to unpredictable outbursts by Walborn et al. (2006) in ACS ISR 2006-04. If there is any question or uncertainty involving Bright Object checking and use of the BOT tool, and in case any policies have changed over time, it is always a good idea to check with the assigned Program Coordinator and/or Contact Scientist or the Help Desk if need be to verify that the correct checks are being made in the correct way and that all the correct current procedures are being followed.

The sensitivity of the ACS/SBC has declined somewhat over time, up to about 9% since installation of ACS in 2002, and at a rate of about 0.5% per year since 2007. This is documented by Avila et al. (2019a) in ACS ISR 2019-04.

It must be noted, however, that there is a Red Leak associated with some SBC filters which will affect magnitude and throughput estimates in some filters. **Also, most critically, as of May 2019, an error in the SBC throughput curves was discovered. The curves were formerly underestimated by about 30%, making Bright Object Protection checking even more important. Some published magnitudes from before mid-2019 or even a bit later may be substantially in error.** New throughput curves have been derived and have been compared to the earlier ones. Please see the ACS Space Telescope Analysis Newsletter (STAN) for October 2019 at http://www.stsci.edu/contents/news/acs-stans/acs-stan-october-2019 and ACS ISRs 2019-05 (Avila et al. 2019b) and 2019-10 (Ryon et al. 2019) for more.

XII - SBC Operating Temperature: Optimal Observing Durations; LOW-DARK Aperture

After about 2 hours of the SBC being turned on, it reaches a temperature at which the dark rate becomes elevated over the FOV of most of the detector. However, there is a corner of the SBC detector where the dark rate remains constant at all temperatures. The use of this aperture places the target coordinates at a location in this corner of the SBC detector. This is especially useful if the principal target at those coordinates is of small enough angular size to fit within the low noise region and if the SBC has to be turned on for a longer time for observational purposes, etc. Generally, any user who needs to observe for longer than ~2 orbits at a time should consider using this aperture if the target area of interest is small enough to fit within the SBC-LODARK aperture area. There is a small cluster of (currently 4) bad pixels which always have elevated counts which are inside the SBC-LODARK aperture and which are marked as bad in the data quality arrays. Users should discard those in processing. See more information on other SBC apertures in the section on the various ACS apertures farther above. Please also see ACS ISR 2018-07 (Avila et al. 2018) and references therein for more on these matters.

XIII - SBC General Concerns; Bad Pixels; Repeller Wire

There is a group of bad pixels in the SBC detector which one may wish to avoid, (see above) and one would also generally avoid placing a prime target on the repeller wire although the images of some larger objects in the field may often unavoidably fall onto the repeller wire. There is more about the repeller wire and the SBC apertures in subsection **i** of this ISR, the subsection on apertures.

XIV - Scattered Light and Ghosts; Dragon's Breath; Chip Gap Glints; CCD Column Bleeding; Diffraction Spikes; Crosstalk

Light may be scattered from brighter stars either in or near the field of view in some cases. If a bright star is on or near the Amp D quadrant of the ACS/WFC detector, a series of ghost images may be propagated diagonally across the chips, often looking somewhat like a number "8". The Amp D quadrant is the one farthest from the WFC3 in the *HST* focal plane. One of the most prominent of several scattered light effects is known as "dragon's breath", and it can be particularly bad in some locations if a star is bright enough. Glints can also be cast across the field of view from the light from stars hitting some tiny reflective bit of material on the edge of the inter-chip gap on the ACS/WFC. Bright stars on the field of view may cause CCD column bleeding on the chip as well as bright diffraction spikes which may obscure or affect the image of some other object(s) of interest nearby on the chip. Even some stars just off the field of view may sometimes cause diffraction spikes to appear on the image in some areas of interest near the edges of the field of view. These and more image anomalies are particularly described in two ISRs and other documents (e.g. Hartig et al., 2002) and referenced therein: HLA/ACS ISR 2008-01 (Stankiewicz et al. 2008) and ACS ISR 2016-06 (Porterfield et al. 2016.) The latter also includes means of estimating such potential effects from bright stars in the area of planned observations, utilizing archival data to estimate the level of the effects which may be expected. Please also note the special web page on ACS Anomalies and Artifacts at http://www.stsci.edu/hst/instrumentation/acs/performance/anomalies-and-artifacts and links from there to various documents relating to ACS image anomalies and scattered light effects, and tools for assessing the likelihood of scattered light problems.

Most of the documentation here has focused on the ACS/WFC, however an optical ghost was also detected in the ACS/SBC F122M filter. For more on that, please see

Collins et al. 2007 (ACS ISR 2007-05).

Electronic crosstalk between different quadrants of the detectors, although not a scattered light effect, can sometimes cause (usually) faint images of bright sources to additionally appear in quadrants other than the one containing the primary offending image. The effect is usually not significant in most ACS/WFC science applications, but it can sometimes be seen. There is more about crosstalk in ACS/WFC detectors since Servicing Mission 4 (SM4) with additional references to pre-SM4 observations as well in Suchkov et al. 2010 (ACS ISR 2010-02).

XV - Special Requirements: Visit-Level and Exposure-Level Requirements

Both Visit-level and Exposure-level Special Requirements exist. These special requirements address and help define a variety of issues such as ORIENT-related requirements, POS TARG requirements for manual dithering specifications or some manually-defined mosaic offset positions, timing requirements, GROUP and SEQUENCE requirements for specific ordering of observations, Guide Star guiding modes and tolerances, CVZ, LOW SKY, SHADOW, and the like, covering a wide variety of types of topics and observing instructions. Like Optional Parameters, some Special Requirements may be restricted in their usage and may require special permission to use. Please see the Phase II Proposal Instructions for more details. The GO text has the Special Requirements most frequently needed or used, while the Engineering text (in red, magenta, and green) also has more information on the more unusual ones which are usually restricted and usually require extra justification and special requests to use.

XVI - Visit Size – How Many Orbits per Visit?

Visits of 1 or 2 orbits are highly preferred by the schedulers due to greater flexibility for the Long Range Plan (LRP) and greater ease of scheduling for the weekly calendar builders. Essentially, visits of 1 or 2 orbits in length are often considered as high-priority "Super-SNAPshots" because of the relative ease and flexibility of scheduling which they allow. Due to limitations on SAA passages intersecting orbits, 5-orbit visits are typically the longest viable visits in most circumstances, but they do not allow so much flexibility. Typically, 4-orbit visits are the least favored by the schedulers since they very inefficiently use most of a 5-orbit period without leaving time for much else except a 1-orbit visit. While some long visits are still done for planetary transits, they take a lot of planning and implementation work. As a result of recent gyroscope issues, HST cannot execute more than two consecutive orbits on moving targets. There has to be a one-orbit gap after every two orbits of moving target observations to get a gyro bias update and full OBAD or on-board attitude determination (Denise Taylor 2019, private communication).

Pointing and tracking issues also can come into play to a greater or lesser degree depending on visit size (number of consecutive orbits), whether using the default guide star pair scenario for guide star acquisition and tracking versus using single guide star acquisition and tracking, and whether breaking a longer visit up into shorter visits and doing separate different guide star acquisitions which may or may not be separated by each other by slews to and from other targets at various places in the sky in the interim. More information on issues such as this is covered in the HST Primer for each new observing cycle for the most part, and the Primer is linked from the main HST documents, and in particular the Call for Proposals and Phase I documents.

SBC visit size has already been discussed above in section **xii**, but in general, after about 2 hours of being turned on, most of the SBC detector begins to suffer from an elevated dark rate. As noted farther above in that same section, a special aperture has been designated which can be used to help mitigate this where feasible given the nature of the target and the field of view.

XVII - WFC Subarrays: How They Can Help and How They Can't

Some previous users of ACS may remember that originally, there were sub-arrays which were defined for ACS/WFC and the calibration files for them could essentially be simply chopped out of the same area for the larger full-frame ACS/WFC calibration files. However, due to the new post-SM4 electronics, the characteristics of the subarray data were not amenable to having their calibration data taken from the same-area subset of the full-frame data and special subarray calibration observations had to be performed to ensure proper calibration. More recently, new subarray readout patterns were defined for the ACS/WFC, and now the subarray data can be run through the standard pipeline calibrations. For more details on this, please see ACS ISRs 2017-03 (Golimowski et al. 2017) and 2017-06 (Bellini et al. 2017) and references therein.

Note that while the use of subarrays will allow storage of more images in the on-board storage before readout has to occur, it will not save overhead time to take and just read out only a 2 or 3 subarray images since the time is the same as for the full-readout. There is more on these overhead times in Chapter 8 of the ACS Instrument Handbook.

5. Web page on current ACS observing advice

In conjunction with this ISR, we have created a web page containing the most up-to-date ACS observing advice since both conditions and best practices can sometimes change over time as the condition of the instrument and the telescope change. Although it is "bulletized" or broken into more pieces in format than this ISR, we link from the web page to this ISR for those who wish to reference an ISR when documenting more details regarding the reasons for their decisions relative to our advice. We aim to keep the two in synch with each other in terms of any **major** updates, **however, over time, the ISR may become somewhat more out of date, and at any given time, the web page is much easier and quicker to update and is therefore likely to be the more up-to-date of the two documents.** The ACS observing advice web page is linked from the general page for ACS proposing at http://www.stsci.edu/hst/instrumentation/acs/proposing and is available directly at https://hst-docs.stsci.edu/acsoam .

6. Conclusions

We have described and discussed the major issues which we have found to be most frequently encountered or most problematic when not addressed sufficiently. This article reflects the collective experience of many observers and ACS Instrument Scientists who review accepted ACS observing programs to ensure that the instrument is being used safely, efficiently, and wisely to obtain the best data for doing the desired science.

7. Recommendations

Since information is periodically updated as conditions and details of the operating state of instruments and the telescope change from time to time, we strongly recommend that those considering using ACS consult all the available documentation - the ACS Instrument Handbook, the ACS Data Handbook, and the ACS-specific or related portions of all the various Phase I and Phase II documents, as well as the ACS-related portions of the Phase II Proposal Instructions, and the ever-growing list of ACS Instrument Science Reports (ISRs) and ACS Space Telescope Analysis Newsletters (STANs). Doing so should provide a more complete understanding of the current state of the instrument and its operations and data output and any concerns for proposers and observers. As stated above, we have also added an on-line web page with periodically updated current advice linked from our ACS web pages at STScI, although much of the advice given in this ISR and on that page will remain true for the lifetime of the ACS and HST.

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Other Resources:

ACS Observing Advice Web Page (HDOX-format web page version of this ISR document): https://hst-docs.stsci.edu/acsoam

ACS ISRs: http://www.stsci.edu/hst/instrumentation/acs/documentation/instrument-science-reports-isrs

ACS STAN Newsletters:
http://www.stsci.edu/hst/instrumentation/acs/documentation/stsci-analysis-newsletter-

stan

ACS Posters: http://www.stsci.edu/hst/instrumentation/acs/documentation/conferenc-posters

Data Analysis Toolbox: http://www.stsci.edu/hst/observing/post-observation/data-analysis-toolbox

DrizzlePac: http://www.stsci.edu/scientific-community/software/drizzlepac.html

STAK Jupyter Notebook Tutorials: https://stak-notebooks.readthedocs.io/en/latest/

Jitter and Pointing: http://www.stsci.edu/hst/instrumentation/focus-and-pointing/pointing

aXe: http://axe-info.stsci.edu/

aXeSIM: http://axe-info.stsci.edu/simulate

HST Data Handbook: https://hst-docs.stsci.edu/display/HSTDHB

ACS Data Handbook: https://hst-docs.stsci.edu/display/ACSDHB

ACS Instrument Handbook: https://hst-docs.stsci.edu/display/ACSIHB/

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