

ACS Default (Archival) Pure Parallel Program

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ABSTRACT

We describe the initial default non-proprietary pure parallel program for the Advanced Camera for Surveys. We describe the observing sequence and outline scientific questions that may be addressed with the data. This report is an update to, and revision of, the earlier ACS/ISR 2000-02.

1. Overview

We describe the initial ACS default or archival (STScI) non-proprietary pure parallel program as conceived for implementation in Cycle 11. This report supersedes a previous version (ACS/ISR 2000-02) and is based in part on feedback received during the ACS High Latitudes Workshop at STScI, March 2001. Pure parallel ACS observations are obtained when an instrument other than ACS is being used to make primary observations (i.e. not auto-parallels which are internal to the ACS, nor coordinated parallels which were requested to be obtained as part of the primary proposal).

Our goals are to provide high quality scientific return and uniformity of data in conjunction with simplicity of implementation and execution. We propose cosmological and Galactic scientific projects that may be addressed with the identical exposure sequencing. All observations use the ACS Wide Field Camera (ACS/WFC) and explicitly disable “auto parallel” observations with the High Resolution Camera (ACS/HRC) in order to retain the flexibility of variable exposure time.

Our strategy is to obtain single filter (cosmic ray split) images per orbit (apart from the one-orbit case where two filters will be used) with a filter change as successive orbits are added, using the Sloan survey filters in the order i , z , g , r . For longer opportunities, the

sequence is cycled repeatedly in order to accumulate substantial exposure time and make “deep fields”. Given the dependency on the primary observation, we assume that dithering is not an option. We propose, for the case of single orbit opportunities, to split the observation between the Sloan i and z bands, and to use a minimum exposure time of half orbit using Sloan i . The specifics of the observing strategy are given in Appendix 1, and other technical considerations form additional Appendices.

Note that there is no “special object” component to the archival ACS pure parallel program and the observational strategy is independent of Galactic latitude.

The Cycle 11 Call for Proposals may be consulted for policies and procedures relating to possible GO applications for pure parallel observing or for uses of the archival pure parallel data.

2. Scientific projects

2.1 ACS as a survey instrument

ACS is a true survey instrument. By design, it is capable of answering important cosmological questions through relatively wide-field deep imaging at high spatial resolution. Specifically, the camera was optimized for studies of (1) the formation and evolution of galaxies and clusters of galaxies, and (2) the nature and large scale distribution of matter in the Universe. Given its unique status on HST as a survey instrument, parallel observations are potentially more important for ACS than other instruments. ACS has a wider field of view, higher spatial resolution and better sensitivity than the WFPC2. In terms of “discovery space” (the product of FOV and sensitivity) it exceeds WFPC2 by a factor of ten, by design.

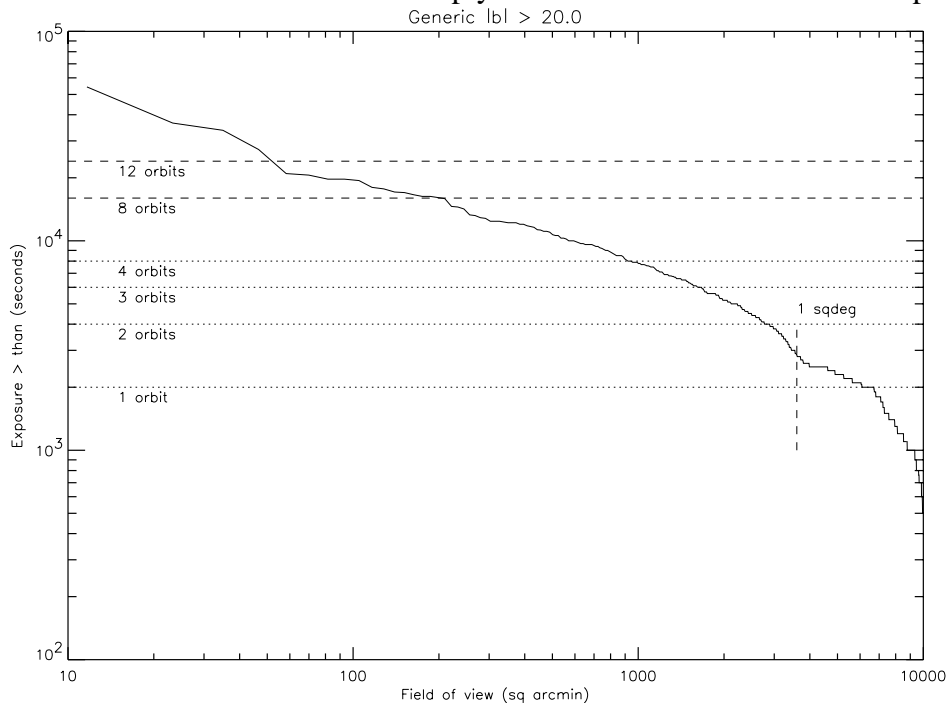
Cosmological studies with ACS will include measurements of weak lensing, galaxy color and morphology evolution, clustering evolution and searches for very high redshift objects. The ACS GTO program, for example, is devoted primarily to a survey targeted at specific galaxy clusters of different redshifts. Pure parallel observations offer the opportunity to greatly increase cosmological survey exposure time and provide a scientific complement to the GTO program through field observations rather than clusters.

On the assumption that ACS will take over from WFPC2 as the preferred imaging camera, and on the assumption that, in general, NICMOS observations will be dithered, we conclude that the majority of ACS pure parallel opportunities will be with STIS spectroscopy prime. This is currently the situation for WFPC2 and, hence, as a model for the distribution of parallel observing opportunities we may assume that the WFPC2 experience is representative. Examination of the available WFPC2 parallel data shows that there is a significant number of opportunities in excess of 10,000 sec which offers the prospect of very deep images. Also, well over a (non-contiguous) square degree has been imaged to lesser depth. That is, the total area on the sky covered by WFPC2 pure parallels of order an orbit in duration exceeds a square degree. In one orbit, the effective Sloan- i magnitude

limit for ACS is expected to be close to 27. Additional statistics on the existing parallel programs may be found following the links in <http://archive.stsci.edu/hst/parallels/>. With a single orbit 2400 sec observation, the approximate ACS/WFC point source $5\text{-}\sigma$ flux limits are, for a flat (flambda) continuum and three exposures:

| Filter | VEGAMAG | ABMAG |
|--------------------|---------|-------|
| SDSS-i (F775W) | R=27.4 | 27.7 |
| SDSS-z (F850LP) | I=26.6 | 27.1 |
| SDSS-g (F475W) | B=28.0 | 27.9 |
| SDSS-r (F625W) | V=27.7 | 27.9 |

These limits are probing to cosmologically useful depths. (The limits are approximate and do depend on the color of the object, ranging over about 0.5 mag with color extremes.) To support the ACS High Latitudes Survey Workshop, March 2001, statistics for the WFPC2 parallel programs of Cycle 8 and 9 were generated. Proposals 8059, 8061, 8436, 8544, 8883, 8090, 8805 cover the years 1999 and 2000. There are over 7000 individual exposures, 2800 orbits, amounting to 5.6×10^6 seconds. For the high latitude portion only, there is 1.7 square degree covered to a depth of one orbit (assuming ACS field of view), 900 arcmin^2 in four orbits which would imply all four Sloan filters in the ACS program.



2.2 A Weak Lensing Survey Using ACS Pure Parallel Observations

Mapping the large-scale structure (LSS) of the universe is a fundamental goal of modern observational cosmology. Up until recently, efforts to do this relied upon identifying visible tracers (i.e., galaxies or clusters of galaxies) of the underlying mass distribution and making the assumption that light traces mass. This approach requires that one understand all the physical biasing effects that this indirect mapping technique implies and, unfortunately, these are not well understood. It is, thus, much better to trace the mass distribution directly. This can be done using large-scale weak gravitational lensing where the mass is mapped by measuring the large-scale correlated ellipticities induced in the images of distant galaxies.

An ACS pure parallel program covering a total (but non-contiguous) area of at least 1 square degree, and to a depth typical of a 1 or 2 orbit exposure, would be able to achieve at least a $10\text{-}\sigma$ detection of the characteristic shear signal on arcmin scales. The detection could be extended to even larger scales, if the field-to-field spacing is ~ 1 degree or so. This S/N estimate assumes the background galaxy density is in the range $1 - 2 \times 10^5$ galaxies per square degree which corresponds to a limiting I-band magnitude in the range 25 - 26, which is easily achievable with ACS/WFC in one orbit, even if the exposures are split between i and z and both filters are themselves CR-SPLIT.

As the area covered in the parallel survey grows, the constraints one can make on the mass distribution will become more sophisticated. Whereas a 1 square degree survey can firmly measure the shear, a survey of 5 or more square degrees would allow a tight constraint to be made on the large-scale angular power spectrum and on ω and λ . The area covered by an ACS pure parallel program over the course of 2 to 4 years, based on the historical data from WFPC2, would be in the range 2 to 5 square degrees. ACS is particularly well suited to such a study because the S/N of the shear signal grows as the square root of the total area and directly with the number of background sources available. The wide format and high sensitivity of the WFC thus make ACS an ideal detector for this application.

2.3 Galaxy Morphology and Evolution

Parallel observations obtained in random fields particularly at high Galactic latitude may be used to study the detailed properties of faint galaxies, specifically their size, color and morphology in different bands. This program would be able to map the number, angular size, color, and morphology of galaxies at cosmologically significant redshifts. As additional colors are introduced into the sequence, photometric redshift estimates may be obtained for redshifts up to approximately 1. Beyond that, there is the possibility of detecting galaxies at very high redshift in significant numbers using the ‘‘Lyman dropout’’ technique, as the flux essentially vanishes below the Lyman limit. The good ACS/WFC spatial sampling in the optical should optimize the ability to achieve star-galaxy separation and galaxy classification at the faint end of the apparent luminosity distribution.

Armed with knowledge of the number counts and colors and, for a subset, a statistical estimate of the redshifts, we may make progress on studying the evolutionary history of galaxies and star formation in galaxies, as well as the clustering properties of galaxies as a function of redshift.

Following WFPC2 and STIS investigations, the ACS default parallel survey will enable studies of:

- the faint galaxy population, their colors and counts as a function of morphological type, thereby constrain galaxy evolution beyond the levels where it can be addressed spectroscopically.
- the sub-kpc rest frame morphology and color gradients of faint field galaxies to constrain stellar populations and dust.
- the morphology of galaxies in the rest-frame UV across a wide redshift range to give a better understanding of the evolution of morphology and star formation properties with redshift.
- the morphology, size and color of the numerous, possibly sub-galactic blue compact objects found at $B \sim 24$
- Lyman dropouts. At the magnitudes that can be reached easily such galaxies will be luminous high-redshift objects and, therefore quite rare. Large, randomly pointed surveys such as the pure parallel program offer a good opportunity to find these objects.

2.4 High Redshift Supernovae

The ACS pure parallel program provides an opportunity to perform an innovative search for ultra high-redshift type Ia supernovae (SNe Ia), objects of unmatched cosmological utility. SNe Ia at $1.5 < z < 2.0$ provide a powerful test of the currently favored accelerating Universe model (or vacuum energy) by tracing the expansion history back to a time when the Universe should be decelerating (Riess et al. 2001).

Current searches for high-redshift SNe Ia use the method of image differencing to find new sources. However, it may be possible to detect very high-redshift SNe Ia in ACS pure parallels with a single epoch because of the unique region of color-magnitude space these objects inhabit. SNe Ia in the desired redshift range will appear as unresolved sources and peak at i -band magnitudes of 25.5 to 27.5 and $i-z$ colors of ~ 1 (J. Tonry 2001 private communication; P. Nugent 2001 private communication). Such sources could be confused with Galactic stars: limiting to explorations of high-Galactic latitude fields, Galactic stars are expected to out-number SNe Ia by a factor of about 10. However, the expected $I-Z$ colors of galactic stars in these I -band magnitudes (predominantly bulge stars due to the high galactic fields) range from 0 to 0.6 with none, except perhaps for brown dwarfs or L-stars, as red as the SNe Ia. For many SNe it may not be possible to separate them from the light of their hosts. But with HST's resolution, experience shows that a good fraction of high-redshift SNe Ia can be cleanly separated. In the ~ 1 square degree of expected ACS pure

parallels ~ 100 such SNe Ia near peak would be expected, so even the discovery of a fraction of these would be a valuable contribution to the current sample.

2.5 Faint Galactic Stars

Parallel opportunities will enable sampling of Galactic star counts with reliable star-galaxy separation as a function of Galactic latitude to constrain Galactic halo/bulge/disk models. The uniformity of the initial survey will enable an unbiased census of the Galactic stellar populations to be obtained regardless of Galactic latitude and to substantial depths. Issues in Galactic structure which can be tackled using ACS data include the spatial extent of the stellar halo, the degree of flattening perpendicular to the disk and whether there is significant triaxial asymmetry. These are all statistical issues with fairly liberal pointing constraints, which render them ideal for parallel observations, particularly since we expect ~ 40 stars/WFC frame to $i \sim 25$.

These analyses require an estimate of distance/luminosity. The individual stars are drawn from different stellar populations and sub-populations, with radically different density distributions; convolved with the volume element, this leads to sampling different absolute magnitudes (for e.g. disk vs halo) at a given apparent magnitude. The simplest means of breaking the ambiguity is to add color information, which the current strategy does for exposures of a single orbit or longer.

Observations lasting several to many orbits will also provide the opportunity for the first short timescale variability survey to $V=28-29$.

Similarly, any multiple orbit images at low ecliptic latitudes offer the possibility of detecting faint solar system objects serendipitously through their proper motion.

The objectives for generic low latitude observing will be similar to previous programs - search for and identify stars at the low end of the main sequence as well as white dwarfs (WD). The high sensitivity particularly in the red region of the spectrum where ACS is optimized, and observations emphasising i and z , will provide a useful diagnostic of late-type and low mass stars, cool white dwarfs and sub-stellar objects to faint limits over a wide field of view.

The existence of brown dwarfs as a unique class has become a reality; nevertheless the transition region linking these objects with the lowest mass stars remains largely unexplored in part because of their intrinsically low luminosities (e.g., GL 229B is only $6.4 \times 10^{-6} L_{\odot}$). Thus, only the nearest examples could have been detected and only small volumes of sky have been searched. The discovery and characterization of both brown dwarfs and transitional objects (e.g., GD 165B) would contribute significantly to topics such as star formation, physical and chemical processes in the region between stellar and planetary atmospheres, "dark matter", and Galactic structure.

High Galactic latitude observations will be well suited to setting empirical constraints on the hypothetical population of WD which microlensing experiments suggest could account for as much as 20% of the dark-matter Galactic halo. Those objects are expected

to have a typical mass of $0.5 M_{\odot}$ and a colour and magnitude that depend on their age. An interesting outcome of recent theoretical modelling of WD cooling sequences is that objects older than ~ 12 Gyr tend to become relatively bluer than at younger ages. This provides a powerful diagnostic for determining the age of both the stellar halo and, potentially, the dark-matter halo. A robust determination of the WD luminosity function at faint magnitudes will represent a key ingredient in our understanding of the star formation process, of stellar evolution and of the nature and origin of baryonic dark matter.

3. Summary

We have outlined the observational strategy to be employed by STScI in providing an archival (default) pure parallel program for the ACS. The program should serve to address a number of important scientific questions, yet remains conceptually simple for implementation and scheduling purposes which should enhance the scientific return through improved survey coverage, both in terms of areal coverage and depth per pointing. The use of the standard Sloan system offers benefits for comparison with other ground based surveys, including of course the Sloan survey itself.

Appendix 1: statement of the specific observations

0.5 orbit: We propose a minimum useful exposure time of one half orbit, approximately 1200 seconds, during which we propose taking one CR-SPLIT direct image (i.e. two images) using the full ACS/WFC camera with the Sloan-*i* (F775W) filter, the most sensitive of the principle survey filters, matched to the ACS peak response and spatial sampling, also ensuring commonality with ground based surveys and future WFC3 surveys. The magnitude limit is expected to be $I \sim 26.3$.

1 orbit: With one orbit available, we propose taking one CR-SPLIT direct image (two images) using the full ACS/WFC camera with the Sloan-*i* (F775W) filter, the most sensitive of the principle survey filters, matched to the ACS peak response and spatial sampling, together with a second CR-SPLIT exposure with the Sloan-*z* filter (F850LP), expected limit $I \sim 26.1$. The exposure will, if technically feasible at the time of implementation, be expanded to fill the one orbit opportunity to best ability. The slightly lower S/N of taking two filter images instead of one is outweighed by the scientific value of the second color, as covered in the science discussion above. Also, addition of the two observations should recover a flux limit comparable to the single filter limit given in Table 1 above.

2 orbits: As for the one orbit case, obtain a Sloan *i* and *z* pair, but now one whole orbit each. High throughput *z*-band imaging is a new capability that ACS brings to HST. Furthermore it is difficult to obtain *z*-band imaging of faint galaxies from the ground due to

the brightness of the night sky at 9000\AA . These z -images over a large area will be ideal for the study of cosmic shear, the two-point correlation function and galaxy morphologies to faint magnitudes as well as providing photometric dropout information for galaxies at very high redshift via the Lyman break dropout technique. An elliptical galaxy with the 4000\AA break straddling the i - z gap has much better detectability in z , hence offering the prospect of a good search for red, high redshift objects. Each of the orbits will have three CR-SPLIT images.

3 orbits: append Sloan- g image (F475W). The higher blue response of the ACS over WFPC2 and good spatial coverage will allow for the discovery of large numbers of moderate redshift galaxies via the Lyman break dropout technique. Scaling from the HDF, we expect to find approximately 13 B-band dropouts per orbit.

4 orbits: append the Sloan r -filter (F625W). Such color information will enable a number of additional scientific studies such as improved cosmic shear and galaxy-galaxy lensing as well as a search for galaxy clusters at redshifts greater than one.

More than four; append appropriate sized visits to accumulate mini-deep field observations. All observations to use Gain=4 to improve data compression on-orbit and hence increase the chances of successful implementation.

Appendix 2 Cosmic Ray statistics

Using Poisson statistics for the arrival rate of cosmic rays, with a rate of 4.32×10^{-5} per pixel per second, a single 1200 second exposure would be impacted by cosmic rays over 5% of its area. Splitting that exposure into two reduces the percentage of pixels that are hit (in this case, twice) to 0.26% for a small loss of S/N due to the additional readout noise, while a third image would result in a negligible fraction of pixels with three coincident hits ($\sim 0.004\%$). Cosmic ray identification may be relatively straightforward given the good sampling of ACS, however identification and elimination are rather different problems. Two images alone still implies over 40,000 unrecoverable (twice hit) pixels, hence we opt for three images as the default for one-orbit integration times. This will give more flexibility in strategies for both identification and elimination of cosmic rays.

Appendix 3 Differential Velocity Aberration

Velocity aberration is corrected in the telescope pointing system for the primary instrument, not the parallel instrument. This differential velocity aberration can cause images to be slightly trailed as the aberration changes around the HST orbit. The latter may impact cosmic shear measurements, following Pirzkal et al 2001, A&A submitted, and Cox Instrument Science Report OSG-CAL-97-06.

If STIS is prime for the majority of ACS parallels, the angular displacement between the two is 672 arcsec. The overall velocity aberration is large, up to approximately 25 arcsec, hence the second order terms can be significant. Typically, over a half orbit, images are trailed by a few tenths WFC pixels, up to a maximum of about 0.8 WFC pixel.

Since separate “jitter” files are built for parallel observations the differential aberration is taken into account when constructing the pointing history and providing the “jitter” information. Hence it is possible to allow for the effect from the data products provided. Also, if there are multiple exposures, the individual exposures will have correspondingly reduced trailing, although there will be a slight image displacement. We do not, therefore, consider differential velocity aberration to be a major concern.

Appendix 4 Data Volume

The report ACS/TIR 2000-03 "HST Data Volume after SM3B" (Colin Cox) estimates the data volume requirements for HST and shows they are dominated by the ACS. It is expected that about 14 Gbit of science data will need to be downlinked per day. Of this, 70 to 80% will come from ACS. That report assumed two ACS parallel exposures per orbit and an optimistic 80% parallel scheduling efficiency. Cox estimated 4.57 Gbit per day of parallel ACS/WFC observing data volume, or with a factor 1.3 on-board data compression, 3.52 Gbit per day.

The WFPC2 pure parallel program, if taken as an analogy for the ACS pure parallel program has approximately 35% of the orbits as single orbit visits and a scheduling efficiency of order 50%. If we optimistically assume an increased efficiency up to 80%, as in the Cox TIR 2000-03, and that the additional efficiency comes from one-orbit visits, then we will have about half the parallel observations as one orbit. If we double the number of exposures in the one orbit case to four, and assume half the program is one-orbit observations, then we increase the parallel data volume to 6.86 Gbit/day, or 5.27 Gbit/day with compression. This increases the total HST data volume requirements to about 17.3Gbit/day, or approximately 157 Gbit/week, or 143 Gbit/week with data compression. The actual technical constraints have not yet been chosen, however it is possible that they may be somewhat conservative and in the ballpark of this figure, leading us to force on-board compression of ACS parallels, or a reduction in the number of CR-SPLITS.