

The HST Advanced Camera Cluster Program

Garth Illingworth¹, Holland Ford², Mark Clampin³, George Hartig³, Marc Postman³, and the ACS science team

¹ University of California, Santa Cruz, CA 95064, USA

² Johns Hopkins University, Baltimore, MD 21218, USA

³ Space Telescope Science Institute, Baltimore, MD 21218, USA

Abstract. Extensive imaging with HST and WFPC2 has resulted in a remarkable increase in our understanding of distant galaxies. The Hubble Deep Fields (HDF-N and HDF-S) have proven to be a "gold mine" for probing field galaxies. Likewise, the surveys of intermediate redshift clusters, through imaging of the cores of a number of clusters or through large-area studies of a few clusters, have provided new insights into the nature of elliptical and S0 galaxies in the cluster environment. However, considerable uncertainty still exists about the evolution, formation processes and formation timescales for ellipticals and the bulges of early-type galaxies. The planned launch of the HST Advanced Camera, the ACS, later in 2001 will result in a dramatic improvement in our ability to characterize galaxies in both the field and in distant clusters. The high throughput, wide-field, excellent sampling, and comprehensive filter complement of the ACS will provide a factor > 10 improvement in HST's ability to quantify the characteristics of large samples of distant galaxies, as well as providing opportunities to investigate the young universe in ways that have not been practical to date.

1 Introduction

Over the last five years we have seen a dramatic increase in our understanding of distant galaxies, both in clusters and in the field. Wide-field imaging with WFPC2 on HST has been central to this progress. We are addressing issues on E and S0 evolution that were previously impossible. The striking numbers of major dissipationless mergers in MS 1054-03 at $z = 0.83$, suggesting that final assembly of ellipticals may have occurred at quite recent epochs, is one example of the value of HST images for this field (van Dokkum – this volume).

The launch of the HST Advanced Camera for Surveys, the ACS, in late 2001, combined with a substantial increase in the number of multi-object spectrographs on large telescopes (like NIRMOS and VIRMOS on the VLT, and DEIMOS on Keck), will result in a further dramatic improvement in our ability to utilize distant galaxies as probes of galaxy formation and evolution in both the field and cluster environments.

2 The Advanced Camera

The Advanced Camera for Surveys, the ACS, consists of three cameras. They are the WFC (Wide Field Camera), the HRC (High Resolution Camera),

and the SBC (Solar Blind Camera). The WFC is optimized for a large field and high throughput in the visible from $\sim 380 - 1000$ nm, while retaining good sampling (50 mas pixels). The HRC incorporates a coronagraph, and is optimized for diffraction-limited imaging with 25 mas pixels and high near-UV throughput, covering from 200-1000 nm with a 29 arcsec field-of-view (FOV). The SBC is optimized for imaging in the UV from $\sim 100 - 200$ nm, with a $26'' \times 29''$ FOV. The Advanced Camera has been described in detail in [1] (and on the ACS website – <http://adcam.pha.jhu.edu/>). Since the most important of the three cameras for studying distant galaxies will be the WFC, more details will be noted here about that camera.

The WFC was developed with the goal of maximizing the throughput for observations in the visible region, particularly around 800 nm where ground-based observations are impacted by the bright sky foreground. The WFC field is ~ 200 arcsec on a side, and covers roughly twice the area of the WFPC2. The pixels are half the size, at 50 mas, allowing essentially the full resolution of HST to be recovered with simple dithering techniques. The throughput of the WFC plus HST OTA will be greater than 40%, largely because of the use of silver-coated optics and high QE, back-illuminated CCDs. This high throughput will greatly improve the scientific capability of HST – the throughput is some $3-5 \times$ better than that of the WFPC2 (see Figure 1). For surveys, where the areal factor can be directly included in the figure-of-merit, the WFC represents a 10-fold improvement over the WFPC2.

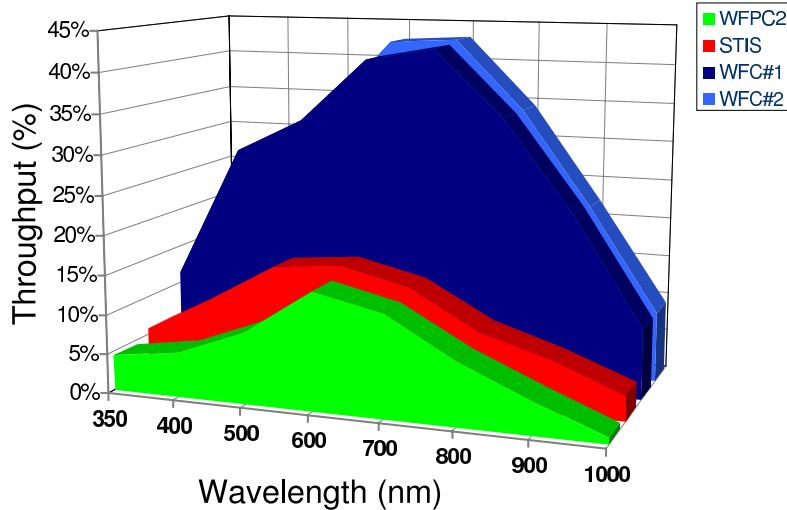


Fig. 1. Expected net throughput for the HST+WFC. The WFPC2 and STIS are shown for comparison with the two CCDs in the current WFC flight camera.

The WFC camera on the ACS also includes a comprehensive set of filters, in addition to the wide band filters that have been extensively used on the WFPC2 (such as F555W, F606W, F814W, etc.). A set that will be of particular interest for intermediate and high-redshift galaxy studies will be the SDSS g, r, i, z filter set. These filters will prove to be particularly valuable for photometric redshift studies, with only very small S/N losses compared to the wider WFCP2 filters. The red pair, SDSS i and SDSS z, will prove valuable for detecting, and constraining the redshift, of very red and/or very high redshift objects. A set of narrow-band ramp filters will provide the opportunity to image with $\Delta\lambda/\lambda \sim 2\%$ FWHM bandpass anywhere from <400 nm to beyond 1000 nm. These will prove particularly valuable for redshifted objects displaying strong emission lines. A broad ramp covering from <400 nm to 1100 nm with $\Delta\lambda/\lambda \sim 9\%$ FWHM may well prove to be valuable for optimized photometric redshift detection of faint, enigmatic objects, or for providing continuum flux measurements between emission lines in sources with extensive line spectra. Several zero-redshift, narrow ($\Delta\lambda/\lambda \sim 1\%$ FWHM) filters such as H α and [O III] have also been included (see [1] and the ACS website for more details).

There are several other features of the ACS that will prove particularly valuable for a number of more specific scientific programs. First, the HRC provides high throughput UV imaging with a scientifically useful set of filters over a limited ($\sim 26 - 29''$ field), though many UV imaging questions can be addressed by such a field size. Second, a set of UV and visible polarizers are included. The high throughput of the ACS makes these more useful than those in previous instruments. Third, a visible grism and a UV (for the HRC) prism add a useful spectroscopic capability due to the low background on HST, even with their low resolution ($R \sim 100$).

3 Distant Galaxy Studies with HST and the ACS

The last few years have seen a remarkable growth in the number of observational programs whose goal is elucidating the nature of distant galaxies. Yet it is clear from the papers at this conference that the growth rate in this field is actually accelerating. A large number of surveys are now being developed to take advantage of the many new large telescopes and/or instruments on the ground, from radio to sub-mm to IR and visible wavelength regions. Complementing this effort are programs that utilize existing or imminent space missions with X-ray (Chandra), visible (HST), and IR (SIRTF) survey capabilities. The uniqueness of the data that can be obtained with these space missions makes them of particular importance for progress in understanding galaxy evolution. HST has played a central role in the last five years because of the unique combination of high resolution imaging over a wide field with very low background levels. It is arguably the single most important pillar for our increasingly sophisticated characterization of the properties of distant

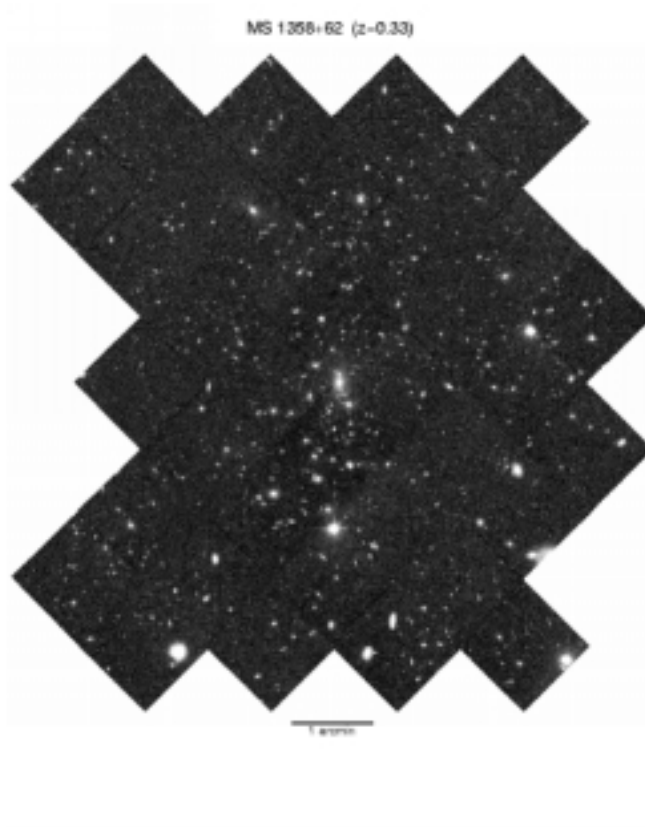


Fig. 2. WFPC2 mosaic of the cluster CL 1358+62 at $z = 0.33$. The image is a mosaic of twelve adjacent HST pointings in two filters as described in [2].

galaxies. No comparable capability is on the horizon until NGST is launched. The dramatic improvements in sensitivity offered by the ACS will even further improve our ability to establish scale lengths for distant galaxies, and to identify the morphological types, sizes, surface brightness distributions and colors of the components of large numbers of individual galaxies. Both visual characterization of morphology, and increasingly sophisticated quantitative definition of the properties of galaxies, will benefit from the higher S/N data that can readily be obtained through the increased sensitivity of the ACS. The larger field, furthermore, allows for improved statistics through larger samples. Clearly ground-based spectroscopic observations will continue to play a key role in addressing the scientific goals, but the options available for obtaining such data are continually expanding. HST remains quite unique.

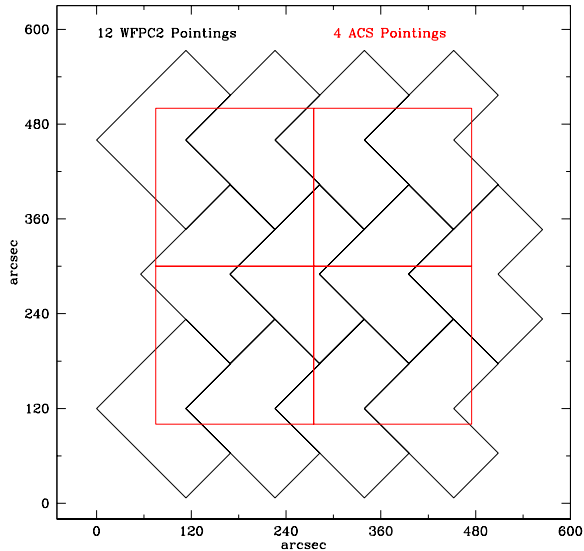


Fig. 3. 12 WFPC2 pointings on the cluster CL 1358+62, compared with 4 pointings of the ACS WFC. A deep, large mosaic like this can be obtained in $< 10\%$ of the time with the ACS with higher resolution.

4 The ACS Science Team's Distant Galaxy Program

The ACS science team is planning to devote around 280 orbits to the study of intermediate-high redshift galaxies. These data would be obtained over a three year period from 2002-2004 after the verification phase following the launch of the ACS as part of the HST servicing mission SM3B in (as currently scheduled) late November 2001. A substantial fraction of these orbits will be devoted to studying the galaxies in intermediate redshift ($z \sim 1$) clusters. The scientific goals of this program include the evolution of the morphological composition and SFR, the relationship between substructure, kinematics and morphology, the history of S0 galaxies, the evolution of elliptical galaxies, the merger type and frequency, the extent of the interaction between galaxies and the ICM, and the nature of brightest cluster galaxies.

This program will be carried out through images of a number of clusters at redshifts ranging from $z \sim 0.8$ to $z \sim 1.3$. The images will be taken through several filters and at contiguous pointings so as to provide areal coverage of the clusters. An example of an areal survey of a distant cluster with the WFPC2 is given in Figure 2. The ability of the ACS to dramatically improve HST's ability to carry out such studies is shown in Figure 3. The four pointings with the ACS cover $\sim 80\%$ of the area of the WFPC2 data, and will result in data of higher S/N in two filters in just 4 orbits.

The ACS distant galaxy survey program also includes a program to image a number of high redshift radio sources ($z > 2 - 3$) that appear to be associated with the development of potentially massive galaxies. These objects could well evolve into the central brightest galaxies in rich clusters at later times. Thus it is particularly interesting to explore their environment and investigate whether significant density enhancements are already becoming apparent at these early times.

The sensitivity, areal coverage and the red (SDSS i, z) filters also will be of great value for studies of red objects, many of which could prove to be at very high redshifts ($z \sim 5 - 7$). A particular focus of the the Science Team's program is the imaging of a sample of intermediate redshift clusters that contain strongly-lensed galaxies, of which some will most likely be at redshifts higher than the $z = 4.92$ arc in CL 1358+62 (Figure 2). These clusters are also of considerable interest in their own right as probes of the dark matter distribution in rich clusters.

5 Conclusion

With an increase in survey efficiency of at least a factor 10, the ACS promises to provide an increase in our understanding of the nature of distant galaxies comparable to that provided when WFPC2 was launched. Even with its aberrated images HST and WFPC1 hinted at the possibilities extant in diffraction-limited imaging over wide fields with modest aperture telescopes in space. WFPC2 confirmed those possibilities with its dramatic deep imaging of the Hubble Deep Fields (HDF-N and HDF-S), and with its extensive imaging of intermediate redshift clusters. The ACS science team looks forward to providing stunning new images of distant galaxy fields in 2002.

6 Acknowledgements

The power that the ACS will bring to HST will be the result of the continuing effort and support of large numbers of highly dedicated professionals within NASA, Ball Aerospace and its contractors, and the science community. We greatly appreciate their efforts on behalf of scientific understanding.

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