Hubble Space Telescope

Cycle 15 GO Proposal

An ACS Treasury Survey of the Coma cluster of galaxies

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Scientific Category: UNRESOLVED STELLAR POPULATIONS
Scientific Keywords: CLUSTERS OF GALAXIES, DWARF GALAXIES, GALAXY FORMATION AND EVOLUTION, GALAXY MORPHOLOGY AND STRUCTURE, SURVEY

Instruments: ACS
Proprietary Period: 0
Treasury: Yes

Orbit Request	Prime	Parallel
Cycle 15	164	0

Abstract

We propose to use the unique spatial resolution of HST and ACS to construct a Treasury imaging survey of the core and infall region of the richest local cluster, Coma. We will observe samples of thousands of galaxies down to magnitude B=27.3 with the aim of studying in detail the dwarf galaxy population which, according to hierarchical models of galaxy formation, are the earliest galaxies to form in the universe. Our initial scientific objectives are:

1) A study of the structure of the dwarf galaxies, including scaling laws, nuclear structure and morphology, to compare with hierarchical and evolutionary models of their formation.

2) A study of the stellar populations from colors and color gradients, and how the internal chemical evolution of galaxies is affected by interaction with the cluster gaseous and galaxy environment.

3) To determine the effect of the cluster environment upon morphological features, disks, bulges and bars, by comparing these structure in the Coma sample with field galaxy samples.

4) Identification of dwarf galaxy samples for further study with the new generation of multi-object and integral-field spectrographs on 8-10 metre class telescopes such as Keck, Subaru, Gemini, and GTC.

This is the first such survey of a nearby rich cluster. It will provide a key database for studies of galaxy formation and evolution, and a very needed reference for comparison with similar galaxy surveys both in lower density environments in the nearby universe, and in high density environments at high redshifts.

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Number of investigators: 32

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Target Summary:

Target	RA	Dec	Magnitude
COMA-CORE-MOSAIC	12 59 48.7000	+27 57 25.00	
COMA-OUTSKIRTS-1	12 56 19.6000	+27 50 5.00	
COMA-OUTSKIRTS-2	12 56 2.1000	+27 49 49.00	
COMA-OUTSKIRTS-3	12 58 33.5000	+27 49 17.00	
COMA-OUTSKIRTS-4	12 56 59.4000	+27 45 16.00	
COMA-OUTSKIRTS-5	12 58 13.9000	+27 44 46.00	
COMA-OUTSKIRTS-6	12 56 29.4000	+27 42 33.00	
COMA-OUTSKIRTS-7	12 57 57.9000	+27 42 0.00	
COMA-OUTSKIRTS-8	12 58 27.4000	+27 41 11.00	
COMA-OUTSKIRTS-9	12 56 3.0000	+27 39 17.00	
COMA-OUTSKIRTS-10	12 56 55.3000	+27 38 42.00	
COMA-OUTSKIRTS-11	12 57 21.9000	+27 38 14.00	
COMA-OUTSKIRTS-12	12 57 42.6000	+27 37 45.00	
COMA-OUTSKIRTS-13	12 58 26.9000	+27 34 47.00	
COMA-OUTSKIRTS-14	12 58 6.9000	+27 33 41.00	
COMA-OUTSKIRTS-15	12 57 46.3000	+27 33 17.00	
COMA-OUTSKIRTS-16	12 56 37.5000	+27 33 13.00	
COMA-OUTSKIRTS-17	12 57 25.9000	+27 31 47.00	
COMA-OUTSKIRTS-18	12 57 22.5000	+27 28 39.00	
COMA-OUTSKIRTS-19	12 57 55.1000	+27 28 42.00	
COMA-OUTSKIRTS-20	12 58 17.3000	+27 27 0.00	
COMA-OUTSKIRTS-21	12 56 46.7000	+27 26 40.00	
COMA-OUTSKIRTS-22	12 57 39.8000	+27 26 17.00	
COMA-OUTSKIRTS-23	12 56 18.9000	+27 25 50.00	
COMA-OUTSKIRTS-24	12 57 4.8000	+27 23 42.00	
COMA-OUTSKIRTS-25	12 58 29.9000	+27 22 51.00	
COMA-OUTSKIRTS-26	12 58 0.8000	+27 22 17.00	

Target	RA	Dec	Magnitude
COMA-OUTSKIRTS-27	12 57 9.3000	+27 14 18.00	
COMA-OUTSKIRTS-28	12 56 28.9000	+27 14 6.00	
COMA-OUTSKIRTS-29	12 58 30.7000	+27 11 49.00	
COMA-OUTSKIRTS-30	12 58 13.4000	+27 09 23.00	
COMA-OUTSKIRTS-31	12 57 38.8000	+27 08 47.00	
COMA-OUTSKIRTS-32	12 58 12.5000	+27 06 17.00	
COMA-OUTSKIRTS-33	12 56 49.1000	+27 05 54.00	
COMA-OUTSKIRTS-34	12 57 4.1000	+27 05 24.00	
COMA-OUTSKIRTS-35	12 57 52.1000	+27 03 29.00	
COMA-OUTSKIRTS-36	12 56 36.6000	+27 03 5.00	
COMA-OUTSKIRTS-37	12 57 29.5000	+27 00 28.00	
COMA-OUTSKIRTS-38	12 57 13.7000	+27 00 17.00	
COMA-OUTSKIRTS-39	12 58 31.7000	+27 00 4.00	
COMA-OUTSKIRTS-40	12 58 16.6000	+26 55 52.00	

Observing Summary:

Target	Config Mode and Spectral Elements	Flags	Orbits
COMA-CORE-MOSAIC	ACS/WFC Imaging F475W		84 (2x42)
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-1	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-2	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-3	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-4	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-5	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-6	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		

Target	Config Mode and Spectral Elements	Flags	Orbits
COMA-OUTSKIRTS-7	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-8	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-9	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-10	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-11	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-12	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-13	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-14	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-15	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-16	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-17	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-18	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-19	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-20	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-21	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-22	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		
COMA-OUTSKIRTS-23	ACS/WFC Imaging F475W		2
	ACS/WFC Imaging F814W		

Target	Config Mode and Spectral Elements	Flags	Orbits
COMA-OUTSKIRTS-24	ACS/WFC Imaging F475W ACS/WFC Imaging F814W		2
COMA-OUTSKIRTS-25	ACS/WFC Imaging F475W ACS/WFC Imaging F814W		2
COMA-OUTSKIRTS-26	ACS/WFC Imaging F475W ACS/WFC Imaging F814W		2
COMA-OUTSKIRTS-27	ACS/WFC Imaging F475W ACS/WFC Imaging F814W		2
COMA-OUTSKIRTS-28	ACS/WFC Imaging F475W ACS/WFC Imaging F814W		2
COMA-OUTSKIRTS-29	ACS/WFC Imaging F475W ACS/WFC Imaging F814W		2
COMA-OUTSKIRTS-30	ACS/WFC Imaging F475W ACS/WFC Imaging F814W		2
COMA-OUTSKIRTS-31	ACS/WFC Imaging F475W ACS/WFC Imaging F814W		2
COMA-OUTSKIRTS-32	ACS/WFC Imaging F475W ACS/WFC Imaging F814W		2
COMA-OUTSKIRTS-33	ACS/WFC Imaging F475W ACS/WFC Imaging F814W		2
COMA-OUTSKIRTS-34	ACS/WFC Imaging F475W ACS/WFC Imaging F814W		2
COMA-OUTSKIRTS-35	ACS/WFC Imaging F475W ACS/WFC Imaging F814W		2
COMA-OUTSKIRTS-36	ACS/WFC Imaging F475W ACS/WFC Imaging F814W		2
COMA-OUTSKIRTS-37	ACS/WFC Imaging F475W ACS/WFC Imaging F814W		2
COMA-OUTSKIRTS-38	ACS/WFC Imaging F475W ACS/WFC Imaging F814W		2
COMA-OUTSKIRTS-39	ACS/WFC Imaging F475W ACS/WFC Imaging F814W		2
COMA-OUTSKIRTS-40	ACS/WFC Imaging F475W ACS/WFC Imaging F814W		2

Target	Config Mode and Spectral Elements	Flags	Orbits
		Total prime orbits:	164

Scientific Justification

Overview – With 164 orbits of HST time using the Advanced Camera For Surveys (ACS), we will survey a substantial area of the Coma cluster of galaxies (740 arcmin^2) in the F475W and F814W bands. The areas selected cover both the core and infall region of the cluster, allowing a detailed study of the properties and morphological transformation of cluster galaxies at $z \sim 0$ as a function of environment. This Treasury program will provide the local "rich cluster" benchmark for comparison to ACS surveys of less dense and relaxed environments (Virgo, Fornax, Perseus), high-redshift HST cluster surveys [66], and field surveys such as HUDF, GOODS, and GEMS.

Coma provides the opportunity to study galaxies in a very different environment to anything previously part of an ACS program. The Coma core is the densest galaxy environment in the local universe. As such, it provides a key reference to study the role of the environment in galaxy formation and evolution. Over many years Coma has been studied at wavelengths from the X-ray to the radio. However, no deep optical images of Coma with high spatial resolution over a wide cluster area exist yet. Only the combined sensitivity, wide area and spatial resolution of ACS at HST can provide these observations. Scientific issues to be addressed include:

- *Measure the luminosity function (LF) down to $M_V = -9$ for comparison with other more nearby clusters. This is critical for detecting dwarf galaxies at luminosities that overlap with the Local-group dwarf spheroidals, and testing whether the faint-end LF slope in clusters is universal.*
- *Measure detailed morphologies using bulge-disk decomposition techniques for a wide range of galaxy luminosities, including those at the faint end of the cluster LF. HST images will also reveal compact nuclei, nuclear bars, disks, and dust rings. Comparison with current results in Fornax, Perseus, and Virgo will outline their dependence upon galaxy density within the cluster.*
- *Derive global colors and color gradients at a range of luminosity and environment to investigate the origin of cluster galaxies, and to understand the environmental process acting upon them.*
- *Investigate the bright and faint ends of the global scaling laws among structural parameters (e.g., luminosity-radius, luminosity-velocity dispersion, fundamental plane) and assess any environmental dependence.*

The proposed survey fits the criteria for a Treasury program: the observations have the potential to solve multiple scientific problems which can only be addressed with ACS data. We intend that the ACS data will trigger complementary observations with other facilities, in particular a large ground-based multi-band and spectroscopic programme. The enhanced data products from ACS and other ground- and space-based facilities will be made available as an integrated resource in the context of Virtual Observatory developments, and will be of broad interest to the community.

The Need for HST – At the distance of the Coma cluster (∼100 Mpc), $0''.1$ corresponds to ∼50 pc. Typical ground-based observations do not have the spatial resolution to resolve and quantify internal structure and features (e.g., star clusters, nuclear rings, nuclear bars, compact disks, nuclear starbursts, pseudo-bulges) at this distance. Moreover, such components, when smeared out by $\sim 1''$ PSFs, are known to have a serious biasing effect on measurements of structural properties [5]. Detection and measurement of globular clusters and ultra compact dwarfs are also seriously impaired by ground-based seeing. Moreover, HST-ACS observations are required to achieve the depth needed to detect low surface brightness galaxies. Finally, HST-ACS images are also required to investigate the presence of partially depleted cores in giant galaxies whose sizes typically range from ~ 40 to ~ 140 pc [74].

Cluster Dwarfs: The Earliest Galaxies – Galaxy clusters are the largest accumulations of matter in the Universe. Unlike the field, they are dominated by early-type galaxies, and host massive, gaseous, X-ray-emitting halos. Their galaxy content is dominated by early-type dwarfs (dE/dS0s) [73,69], which are thus the main, but not the sole, focus of this proposal. The study of dwarf galaxies is important, because *(i)* dwarfs host considerable amounts of dark matter; *(ii)* the popular hierarchical clustering scenario predicts naturally that dwarfs in clusters are the first galaxies to form [79]; regions in which galaxy formation is initiated first are ones whose small-scale density peaks (which become the dark matter halos) are superimposed on underlying large-scale density peaks, which evolve into rich clusters; and *(iii)* Dwarf galaxies have a shallower potential well than giants and, therefore, efficiently probe a wide range of environmental processes. Despite decades of study, we still do not really understand the physics driving the environmental effects on dwarf galaxy evolution. The debate centers around the relative importance of mergers, tidal interactions, and ram-pressure stripping in shaping the morphologies of galaxies, and on the relative importance of supernova winds and black-hole-driven outflows in regulating star formation. For instance, in the "galaxy harassment" model [59], some nearby cluster dE/dS0s may be evolved counterparts of the numerous low-mass blue disk galaxies observed in clusters at intermediate redshifts whose nature/evolution has puzzled cosmologists since their discovery [13]. Tentative evidence in support of this model is the discovery of a spiral structure in a sizeable fraction of cluster dEs [35]. Yet another plausible scenario is that cluster dE/dS0s formed after the cluster's initial collapse, possibly originating from accreted field galaxies [21]. A fraction of cluster dE/dS0s do appear to be only $\sim$ 7 Gyr old and have nearly-solar metallicities [77], consistent with being the remnants of stripped spiral galaxies. Despite the increase in observational data for dE/dS0s in the last decade, the tests to discriminate among this diversity of models are inconclusive, and the formation mechanisms of dE/dS0s remain a mystery. To accurately test the predictions of the existing plethora of models, we will provide a comprehensive dataset with which to study the morphology, structure, and populations for a statistically representative sample of dE/dS0s as a function of their environment.

In what follows we expand upon four key projects to be undertaken with the survey, however the range of the science output is much larger.

The Structure and Scaling-Laws of Dwarf Galaxies – Despite being the most numerous galaxy type in nearby clusters, dE/dS0 galaxies are among the most poorly studied due to their low surface brightness ($22 < \mu_e < 26$ B mag/arcsec^2). Like their more massive counterparts, dE/dS0s exhibit well-defined empirical correlations among global galaxy parameters, such as luminosity, radius, surface brightness, color, velocity dispersion, and line strength indices. These so-called scaling laws can tell us a great deal about the physical processes operating during the early stages of galaxy formation, of which major contributors are star-formation feedback [26], tidal interactions [24], and interactions with the hot intergalactic medium [3,69,76]. The study of the scaling laws in various environments also provides the key observational reference needed to test specific predictions of current theoretical models of dwarf galaxy formation and evolution. For instance, the galaxy harassment model predicts that dE/dS0s in the highest-density cluster regions should have steeper light profiles, the fraction of nucleated dE/dS0s should be higher, the fraction of any remaining disk structure should be lower, and they should have higher metallicities than those located in lower-density cluster environments [59]. Hierarchical models predict old ages and low metallicities for dE/dS0s, especially in high-density environments. Alternatively, younger ages and higher metallicities in lower-density cluster environments would support their evolution from accreted field galaxies. Our team already has line strength indices and velocity dispersion measurements for a couple of hundred dE/dS0s in the two Coma fields described above. The proposed HST-ACS observations will provide measurements of the structural parameters, such as the Sérsic index, half-light radius and surface brightnesses, needed for a comprehensive study of the scaling laws for dE/dS0s galaxies. Comparison between the slope and scatter of these scaling laws for the Coma core and those for the infall region and lower density clusters, will allow to test for any environmental effects on the structural and stellar population properties of these galaxies.

We will also investigate the population of Ultra-Compact Dwarfs (UCDs); a relatively new addition to the family of small stellar systems. To date they have been detected in the Fornax and Virgo Clusters [44], and possibly in Abell 1689 [57]. They range in brightness from $M_V = -13.5$ down to the magnitudes of the brightest globular clusters [23,37]. The origin of UCDs, and indeed their status as a separate class of object, remain obscure [8,27,28,39,59,67]. The study of structural and color parameters of UCDs in a richer environment will test the viability of the proposed formation models.

Color gradients and Stellar Populations – The steepness of the color gradients of dwarf and giant galaxies directly reflects their merging history: monolithic collapse imposes an initially steep negative metallicity gradient [15], which will be progressively diluted by subsequent major mergers [7,48]. Semi-analytic models of hierarchical galaxy formation predict differences in the merger history as a function of galaxy morphology, mass, and environment [17]. In order to provide a complete understanding of cluster dwarfs, it is crucial to acquire a sizable and unbiased sample, so that the global scaling relations of different dwarf subtypes (dE, dS0, dE-N, dIrr) can be reliably determined. Giant Coma ellipticals have metallicities that seem to correlate with galaxy mass, which is broadly consistent with monolithic collapse models [31]. In contrast, dwarf ellipticals display a variety of color gradients, even positive in some places, which is an indication of recent star formation [77]. The survey will provide the first dataset to test detailed predictions for scaling relations and internal color gradients in a rich cluster environment, for a large range of galaxy masses. Complemented by K-band and IFU observations, our ACS images will be used to interpret the observed color distributions in terms of ages and/or metallicities.

Another major outstanding puzzle is the physical origin of post-starburst spectra in distant clusters. Spectroscopic surveys [14] identified several galaxies with post-starburst spectra in the infall region of Coma. Suggestions as to what triggered these bursts range from equal-mass galaxy mergers [6] to high-speed interaction with the dense ICM [64,72]. The key to distinguishing between these processes is the spatial distribution of the intermediate-age populations. It would be concentrated to the center if major mergers were involved [6], while it would be an extended phenomenon if the galaxy had swept through the ICM. The sharp eye of HST is needed to provide a clear-cut answer on this issue, which could provide a breakthrough in our understanding of the evolutionary effects observed in distant clusters.

The Faint End of the Luminosity Function – The logarithmic slope of the low-mass end of the

Cold Dark Matter (CDM) mass function has a slope $\alpha \approx -1.8$. In contrast, the faint end of the field-galaxy luminosity function has a slope $\alpha \approx -1.3$, when measured either from optically-selected surveys [10], or H I [80] or $\alpha \approx -1.0$, when measured in the K-band [17,49]. Luminosity functions in clusters and groups are often not well fit by a single Schechter function, and are better modeled by a combination of a Gaussian and a Schechter function [29]. The composite behavior of the LF and the trends with cluster richness are beginning to be understood in the context of the conditional luminosity function [21], which provides a powerful conceptual framework for exploring the physics of galaxy formation via studies of halos (clusters and groups) of different mass. The suppression of the faint-end slope of the LF relative to the CDM mass function is widely believed to be due to photoionization by the meta-galactic UV background, which suppresses star-formation in low-mass halos. This predicts an environmental dependence [76] because the fraction of dwarf-mass subhalos that collapse before re-ionization is higher in higher mass halos, i.e., much higher in a $10^{14} M_\odot$ halo than in a $10^{11} M_\odot$ halo. This prediction can be tested directly with our survey, as the very faint-end of the LF slope in Coma should be closer to the CDM prediction, and at least some of the dwarfs should have very old stellar populations.

Disks, Bulges, and Bars in the Cluster Environment – The high density in the Coma cluster core makes it an ideal place to investigate the morphology-density relation. We know that average B/D flux ratio and HI depletion increase with galaxy density in Coma [22,11]. Using ground-based imaging, a recent analysis concludes that disks in the Coma core are 30% smaller than in the field for a given bulge size [36]. The ACS data will allow us to dramatically improve the quantitative basis for these statements, as bulge-disk decomposition in the presence of nuclear components depends critically on spatial resolution [5]. The radial dependence of bulge and disk morphologies will constrain the roles of mergers [2] and of disk truncation processes.

It is widely recognized that stellar bars redistribute the angular momentum of baryons and dark matter in disk galaxies, driving their dynamical and secular evolution [50]. From a theoretical standpoint, we expect bars to occur in a dynamically cold, gas-rich disks either spontaneously or under the influence of a satellite companion or minor merger. In cluster environments, high speed impulsive encounters (minor mergers and harassment) and ram-pressure stripping exert competing influences on the formation and destruction of bars. In the proposed program, we will identify unobscured primary and nuclear bars that can be as small as a few 100 pc, and detect nuclear features induced by bars, such as resonance starburst rings, compact disks, and disky pseudo-bulges [50]. The properties (size, strengths, ellipticities) of bars will be characterized using rigorous *quantitative* criteria [43] that were previously applied to several thousand galaxies at $z \approx 0.2 - 1$ from the GEMS survey [68], demonstrating that optically visible bars are abundant out to $z \approx 1$. We will directly compare the derived optical bar properties in Coma galaxies to matched control samples of galaxies in SDSS and GEMS [43].

While observations in the rest-frame I-band (F814W) may miss some highly obscured morphological features, a comparison of the optical properties across field and cluster environments will set important constraints on how environment influences their formation and evolution.

Relation to previous HST surveys – There are a number of existing ACS surveys of galaxy clusters. The largest is the ACS Virgo Cluster Survey (GO 9401–PI: Côté), whose aims are quite different from ours. That survey focused on globular cluster systems in Virgo early-type galaxies, the cores of the bright E and S0 galaxies, and the calibration of the surface brightness fluctuation method for distance scale determination. However, in addition to studying only early-type galaxies, the Virgo survey targeted individual objects and did not cover the intergalactic field. Only as a by-product has the Virgo survey produced a study of UCDs. The Perseus Survey (GO 10201–PI: Conselice) shares some of our aims but is sampling a less relaxed cluster and covers significantly less area. A study of Abell 901/2 (GO 10395–PI: Gray) is of a 7 times more distant system, thus both the imaging and ground-based follow-up have much shallower limits in absolute magnitude terms, and detection of small-scale structure is hampered. Our study of the Coma Galaxy Cluster will be complementary to these surveys, it will sample a dense cluster environment with an unprecedented combination of large coverage, photometric depth, and high spatial resolution.

Existing data on the Coma cluster – Extensive spectroscopic surveys of Coma exist, largely by members of this collaboration. These include redshifts [19, 58], velocity dispersions [16,46,53,60], and line strength indices [14,54,60,61,62]. Independent samples of dwarf galaxies have been defined by Mobasher et al. and Matkovic & Guzmán in two regions of the cluster: the core and the South-West extension near NGC 4839. Both of these regions are targeted in the current proposal. Samples of post-starburst (K+A) galaxies have been defined by [14,64] in the same regions of the cluster. Our team has begun to assemble near-IR photometry of large samples of dwarf galaxies. We intend to undertake a complete JHK survey of the areas covered by the ACS observations using allocations on the UKIRT Wide Field Camera (PI:Lucey). Developments in the future will allow the acquisition of IR data with comparable resolution to ACS, either from ground based adaptive optics facilities, or future space facilities (WFC3, JWST).

As the nearest rich cluster, Coma has been a natural target for observations at all electromagnetic wavelengths. At X-ray wavelengths, deep XMM and Chandra studies of the cluster galaxies and ICM are available [32,78] and have been supplemented by a deep Chandra survey of the infall region (PI: Hornschemeier; [40]). Deep Spitzer MIPS observations of the entire survey region proposed here are published [4] while Spitzer IRAC observations of the infall region in Coma have been obtained by members of our team (PI: Hornschemeier). We also have FUV and NUV GALEX coverage of the entire region (PI: Hornschemeier). We are planning for a large VLA proposal to cover the area of Coma selected for the HST/ACS observations (PI: N. Miller).

Spectroscopic and Infra-Red Follow-Up – We intend to undertake a major campaign of deep multi-object ground-based spectroscopy, mainly aimed at characterising the star formation histories of our galaxies, improving on the first order determination of age and metalicity given by the broadband optical colors. HST is uniquely able to provide the structural information with which to define and classify large samples of Coma dwarfs for complementary spectroscopic observations on the latest, and future, generations of high-resolution, multi-object spectrographs on the largest ground-based telescopes.

Line strength indices from exisiting and proposed spectroscopy provide estimates of stellar population ages and metallicities for a large number of giant and dwarf Coma galaxies. The combination of star formation histories and accurate morphologies will constrain the evolutionary history as a function of galaxy mass [61] and present-day morphology [51, 63] for the first time in the dwarf regime. Thanks to HST, we can test whether the bimodal distribution observed in the metallicities of Coma dwarf galaxies [62] is reflected also in structural differences between the two classes, clarifying the possible different formation channels for low mass galaxies in clusters.

High-resolution near Infra-Red photometry, from ground-based Adaptive Optics facilities, or in the future from WFC3, offers the promise of breaking the age-metallicity degeneracy [42,70]. Combined with the Spitzer observations which are already planned, the effect of the third parameter of dust extinction will be addressed [41] in studies of age and metallicity differences.

The spectroscopic campaign will also provide vital kinematic data. With a larger sample of Coma galaxies with accurate velocities and morphologies, we can compare the velocity distributions of giants, dwarfs, and UCDs, which will assess how far Coma has moved towards equipartition, and the spatial relationship between these three galaxy types [25,36]. We will search for cluster substructure and infalling groups, and thus study the ongoing mass accretion of Coma in the context of hierarchical structure formation models [1]. Furthermore, using a large number of velocities we will constrain the cluster mass density profile and the orbital kinematics of the galaxies themselves [52,55,56].

An important science driver is the faint end of the Fundamental Plane (FP). Being the nearest rich cluster, Coma is the best available z=0 reference for studies of the evolution of the FP with look-back time [45]. The Coma FP has also been used as a for comparison with other galaxy types, such as field ellipticals and bulges of disk galaxies. ACS images, together with new deep spectroscopy, will improve our knowledge in two ways. Structural parameters will be determined with higher accuracy using ACS data, allowing for a better constraint of the role of structural non-homology in the thickness of the FP [75]. Structural parameters will also be derived for fainter galaxies, allowing for accurate studies of the faint end of the FP.

The v/σ_0 vs. ϵ diagram, a classical tool to measure kinematic anisotropy in spheroidal systems, was recently revised [9], highlighting the benefits of 2D spectroscopic information. This new diagnostic tool has been used to show that disky ellipticals, which common lore assigns isotropic velocity dispersions, are in fact strongly anisotropic [12]. The degree of kinematic decoupling may be related to the strength of harrassment processes [33]. We will obtain 2-D spectroscopy of selected Coma dwarfs to determine their degree of kinematic anisotropy. In general, IFUs and multi-slit spectrographs such as Keck/DEIMOS, Gemini/GMOS, VLT/Flames and Subaru/FMOS will be used to study the samples constructed from this survey.

Other Science Projects - We have provided the highlights of the core science program, but other important projects to be undertaken by the team or the wider community include:

Globular clusters – The point source limits are $\sim$ 1.5 mag brighter than the peak of the GC luminosity function, so we are restricted to studying the brightest GCs. However, with imaging for a large number and wide range of galaxies, we can complement existing HST WFPC2 studies on bright Coma ellipticals (e.g. NGC4874 [47] and NGC4839). A very interesting recent development has been the finding of a correlation between colour and luminosity for the brightest blue GCs in several BCGs [38,71], interpreted as a mass-metallicity relation with $Z \propto M^{0.55}$. By stacking the lower-luminosity galaxies, we can test the universality of this relation.

– *Multi-frequency studies of star formation and gas content in the core and infall region of the cluster,* using existing and proposed data from Spitzer, Galex, VLA, Chandra, and XMM.

– *Study of morphological transformation in the core and outskirts of the cluster*, how indicators of current merger activity (shells, ripples, tails) depend upon environmental density.

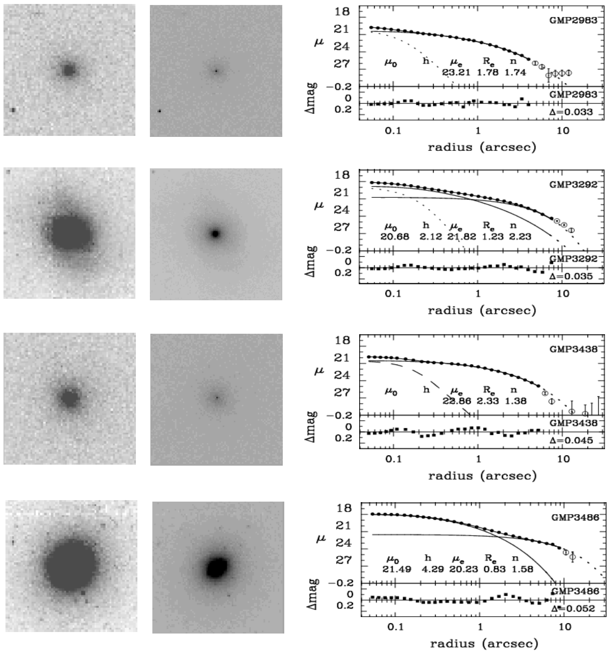

Fig 1. Images and surface brightness profiles of a range of Coma dwarf spheroidals $17.7 < m_B < 20.0$ [34].

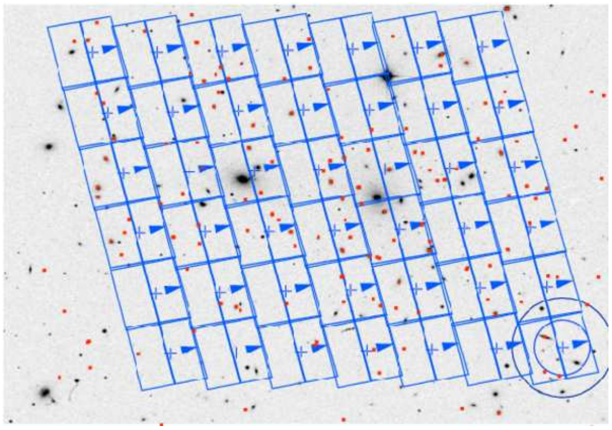

Fig 2. Layout of the ACS observations of the central tiled region of Coma. The dots represent targets from the lists of dwarf and star forming galaxies discussed below.

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Description of the Observations

ACS observations – The goal of this Treasury Project is to provide a legacy of photometric and morphological information on Coma cluster galaxies having a range of absolute magnitude and in a variety of environments. Color information is important to many of the science goals described above, and we have chosen to observe in filters F814W and F475W. The depth of F814W is ideal for the structural work. We have chosen F475W over F606W, despite the longer exposure times required as the colors of single stellar population (SSP) models show that (F475 - F814) is between 2.5 and 3 times as sensitive at detecting stellar population changes, whether caused by age or metallicity, as (F606 - F814).

Survey tiling and targeting strategy – Due in part to the composition of rich clusters, many of the primary science goals involve the analysis of dwarf galaxies. In particular, in addition to a contiguous map of the core region (see below) we target known dwarf cluster members and star forming galaxies from three sources:

1) The Mobasher et al. [58] sample of Coma galaxies with R>16.5.
2) The Florida [53,54] sample of dwarf spheroidal cluster members.
3) The Caldwell et al. [14] sample of galaxies with abnormal (E+A) spectra.

We propose a tiled area of 42 tiles in the core (approximately 21 by 18 arcminutes) plus a further 40 pointed observations in the infall region around NGC 4839 observed spectroscopically by [54,62]. At an orientation of 282 degrees, these tiles can be positioned to include 211 known dwarf cluster members from these lists, and 16 E+A galaxies from [14].

The total survey covers 740 square arcminutes. We propose two orbits per pointing, with an exposure time of 800s in F814W and 2800s in F475W. The sensitivity limits (S/N = 10) are $B_{Johnson} = 27.3$ and $I_{Johnson} = 25.1$ in a 0.2 arcsec^2 aperture. Calculations using the ETC surface brightness limits and detailed surface photometry of Coma Dwarfs [34], predict that the limits for measuring color gradients will be $V \sim 19.5$ ($M_V \sim -15.5$); for measuring detailed structural parameters such as Sérsic indices $V \sim 21$ ($M_V \sim -14$); and for measuring basic structural parameters to distinguish dwarfs from background for constructing samples for deep spectroscopy $V \sim 23$ ($M_V \sim -12$).

Thus our total request is 164 orbits

Scheduling and orientation in two-gyro mode – In two-gyro mode the optimum orientation is 282 degrees; at this orientation Coma is observable with nominal (53 minute) visibility for 46 days in Cycle 15. The tiles in the central mosaic need to be at the same orientation, but this requirement can be relaxed for the targetted observations in the outer infall region, provided that the information on the possible orientations is available at the phase-II planning stage. Splitting the requested time over two Cycles can also be considered if required due to scheduling constraints.

Data Products – The data will be reduced by a dedicated ACS pipeline. Similar to e.g. the Virgo ACS project, the products will include catalogs of galaxies and associated globular clusters, and and their basic properties (e.g., celestial coordinates, magnitudes, colors, and structural parameters), a list of galaxies down to the limiting magnitude, (I = 25.1) and the results of isophotal analysis for each galaxy (radial profiles of surface brightness, color, ellipticity and position angle), as well as extinction maps and dust masses. We will produce color maps using Voronoi binning [30], extending them to much larger radii. To the surface brightness profiles we will fit different profiles, such as Sérsic, or Sérsic + exponential, or Sérsic + exponential + nuclear component [5,34]. We will derive rigorous bar parameters [43], and in the outer parts we will measure the asymmetry, lopsidedness, and outer cutoffs [65]. Results will be published on a project web site.

Data will be ingested in the Astro-Wise system (www.astro-wise.org), a novel astronomical information system which federates both raw and processed data (images and catalogues of sources). The AstroWise system facilitates on-the-fly re-processing both for calibration results and science results, via web-services (www.astro-wise.org/portal). It allows researchers at different locations to share data and the data processing in a common infrastructure. It also facilitates viewing and retrieving of any data item and the association of source lists with other wide-field imaging surveys also ingested in the system (e.g., VISTA, OMEGACAM@VST, MegaCAM@CFHT). For this project the association with results from the MegaCAM@CFHT will be important, and the statistical comparison with results from other planned, deep, modern, ground-based, wide-field imaging of nearby Southern Superclusters such as Horologium and Shapley (the VST VESUVIO project) can be facilitated by Astro-Wise. The Astro-Wise system will be used to publish the results on the internet, both directly through the portal and indirectly through the European Virtual

Observatory (Euro-VO) to which Astro-Wise connects.

Project Management Plan– Overall project management will be the responsibility of the PI, D. Carter, who will be responsible for coordinating workpackages, organising meetings, and maintaining communications. The U.S. Principal investigator is H.C. Ferguson. The project will have four main phases, which will overlap in time:

1) Data taking and distribution phase: Work in this area is split into two workpackages. P. Goudfrooij will coordinate the STScI pipeline workpackage including CR cleaning, registration, flatfielding, photometric and astrometric calibration, and mosaicing. The deliverables of this workpackage will be fully reduced and calibrated FITS images. These will be available to the community within three months of data being taken. The host for the image data archive will be STScI. R. Peletier will coordinate the data products workpackage at Groningen. The input to this package will be the FITS images, and the output will be merged, parametrized object lists containing magnitudes, colors, scale and morphological parameters, and external data (e.g., redshifts, ground-based colors) for all objects in the images. The object lists will be hosted at Groningen, mirrored at Liverpool and at STScI, and will be available within one year of the data being taken.

HST Data Products and Data Release Schedule	
Raw Data	Immediately public on entry into HST archive.
Version 1	Co-added, CR-cleaned, drizzled images of individual fields released within 3 months.
Version 2	Final images reprocessed with best reference files and improved astrometry will be released 6 months after the final observations.
Source lists	Positions and magnitudes released with the version 2 images.
Full catalogs	Catalogs including results of morphological analysis and external data (redshifts and ground-based colors) for all objects will be released one year after the last observations.
Coma Public Datasets expected from other facilities	
Deep Spectroscopy	Bridges/Hudson/Tully/Okamura (Gemini/Keck/Subaru).
IR Spectroscopy	Balcells/Guzmán (GTC La Palma).
IR Imaging	Lucey/Smith (UKIRT/VISTA).

2) Science Exploitation Phase: Overall responsibility rests with the PI to achieve a consensus on the division of science goals within the team. Two team papers will be published on methodology (led from STScI/Liverpool and Groningen respectively) and at least six on the science goals listed in the paper. Project science meetings will be held every six months, alternately in Europe and on the east coast of the USA. These meetings will be open to new participants in the project. The Science Exploitation Phase will last for two years from the start of observing, at which point effort will be transferred into the followup phase.

3) Outreach Phase: This is divided into two workpackages: public outreach and community outreach. Public outreach will be led from STScI with considerable input from Liverpool. STScI will develop visual materials, and Liverpool will use the facilities of the National Schools Observatory (NSO, and the International Schools Observatory, both hosted by Liverpool John Moores, to develop material for use in education. The NSO has a custom image processing program, LTImage, developed for UK secondary (age 11 - 18) schools to enable students to analyse and appreciate astronomical images. NSO products involving Coma cluster data would be made available in the US through STScI, and would be translated into languages other than English by the host institutions or national agencies of members of the team. Community outreach has the goal of enhancing the exploitation of the Coma dataset, and would be the responsibility of the PI. The primary means of community outreach would be project science meetings, which would be open, and at each meeting there would be at least one invited contribution from someone outside the team. The outreach phase will be concurrent with the Science Exploitation Phase.

4) Followup Phase: Ground based and other wavelength followup is important to the success of this project. Deep optical spectroscopy, and infra-red imaging and spectroscopy in particular are key. The PI will be responsible for ensuring coordination of the science goals and avoiding duplication. Expected companion programs and leads are listed in the table above. All data sets will be public with schedules (relative to the observations) simlar to the HST data.

■ Special Requirements

■ Coordinated Observations

■ Justify Duplications

At the distance of Coma, the typical half-light radius of dE/dS0s is 1 – 3″. Accurate measurements of the structural parameters can only be done using HST.

In a pilot programme, members of the team have already analyzed all suitable archival HST (WFPC2) images of dE/dS0 galaxies in Coma [34]. The detected nuclei are unresolved at the 0.″1/pix resolution of the WF chips of the WFPC2 images. The factor two higher spatial resolution of ACS/WFC is vital. It is vital to construct a large and representative sample, which the proposed survey will do.

In the Coma cluster, the only ACS observations are for GO10397 (PI:West), a deep study of a single field to detect intergalactic tidal debris, and GO9274 (PI:Gregg), an I and Hα study of an individual luminous spiral galaxy. There are a number of WFPC2 observations: GO5997 (PI:Lucey) a survey of short exposures of the cores of bright elliptical galaxies, which provides the raw data for the preliminary study described above; GO6104 (PI:Harris), GO8200 (PI:Harris) and GO8184 (PI:Côte), deep studies of the globular cluster systems of the cD and giant elliptical galaxies in the cluster; GO6773 (PI: Rose), a multi-waveband study of a small sample (4 in Coma) of the poststarburst galaxies; and GO8645 (PI:Windhorst), a mid-UV observation of an individual cluster galaxy. Most of these observatiosn are too shallow for our purposes, and all target individual bright galaxies, so none provide the wide area survey and large samples of galaxies that we need. However the deep WPFC2 observations of globular cluster systems of giant galaxies will provide a valuable comparison with our GC observations of cluster dwarfs.