CFHT [2008B - 2012B] Large Programs
First Call
Deadline: 1 Feb 2008 - 24:00 UTC

Title	**The Next Generation Virgo Cluster Survey (NGVS): A Comprehensive Study of Baryonic Substructures in the Low Redshift Universe**
Abstract	The Virgo Cluster is the dominant mass concentration in the local universe and the largest collection of galaxies within ~35 Mpc. As the most thoroughly studied cluster in the universe, it is the target of many ongoing and planned surveys at X-ray, UV, IR, submm and radio wavelengths. However, the best existing optical survey of the Virgo Cluster — the photographic Virgo Cluster Catalog of Binggeli et al. (1985) — is now nearly a quarter century old and hopelessly out of date by modern standards. We propose to capitalize on the wide-field imaging capabilities of MegaPrime to carry out the *Next Generation Virgo Cluster Survey*: a programme to survey the cluster from its core to virial radius, in $u^*g'r'i'z'$, to a point-source depth of g'~25.7 mag (10σ) and a corresponding surface brightness of $\mu_{g'}$ ~ 27.7 mag arcsec^{-2} (2σ). The NGVS will completely supersede all existing optical studies of this uniquely important system, and, by leveraging the vast amount of data at other wavelengths, will allow us to address a wide range of fundamental astrophysical questions, including: the faint-end shape of the luminosity function, the characterization of galaxy scaling relations over a factor 10^7 in mass, the cluster/intracluster medium/galaxy connection, and the fossil record of star formation and chemical enrichment at z~0. Numerous ancillary projects — from a survey of the Galactic halo to cosmic shear measurements — will also be enabled. The NGVS will be a lasting legacy of CFHT: not only will it be the definitive study of baryonic substructures in a low-z cluster environment, but it will yield the benchmark observational database against which the next generation of hierarchical formation models will be tested.
PI Name	Laura Ferrarese
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PI Institute	National Research Council of Canada, Herzberg Institute of Astrophysics
Co-Is (Name, Institute)	Our CoI list cannot fit in the space provided, and has therefore been included separately in the cover page of the main proposal.

Total number of **hours** requested	771	**Hours per agency:**	Canada	325	France	325	Hawaii	121	Taiwan	0

Proprietary period for participating community access is zero by *default* (free immediate access).
If you want this proprietary period to be set to a specific time, provide below the time period and justification for the request.

- All participating Agencies will have immediate access, through the Canadian Astronomy Data Centre (CADC), to the raw images, as well as to the pre-processed and stacked images and source catalogues produced by Elixir, MegaPipe and Terapix.
- All processed data created using pipelines built within the collaboration will be released internationally once the primary objectives of the survey have been achieved by the team, and no later than two years after the completion of the survey.

Proprietary period for World Access is by *default* one year after the end of each semester for the duration of the survey.
If you want this proprietary period to be changed, provide below a data release schedule and a justification for the request.

- The international community will have access to the raw data one year after acquisition, and to Elixir, MegaPipe and Terapix data products one year after the completion of the survey (2013).
- To enhance the synergistic opportunities of the survey, throughout the duration of the NGVS, the team will remain open to collaborations and sharing of proprietary data with other consortia.

Observing Proposal in Response to CFHT's Call for Large Programmes

Semesters: 2009A, 2010A, 2011A, 2012A

Agencies: Canada, France, Hawaii

The Next Generation Virgo Cluster Survey (NGVS): A Comprehensive Study of Baryonic Substructures in the Low Redshift Universe

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Abstract: The Virgo Cluster is the dominant mass concentration in the local universe and the largest collection of galaxies within ~35 Mpc. As the most thoroughly studied cluster in the universe, it is the target of many ongoing and planned surveys at X-ray, UV, IR, submm and radio wavelengths. However, the best existing *optical* survey of the Virgo Cluster − the photographic *Virgo Cluster Catalog* of Binggeli et al. (1985) − is now nearly a quarter century old and hopelessly out of date by modern standards.

We propose to capitalize on the wide-field imaging capabilities of MegaPrime to carry out the *Next Generation Virgo Cluster Survey* (NGVS), a programme to survey the cluster from its core to virial radius, in $u^*g'r'i'z'$, to a point-source depth of $g' \sim 25.7$ mag (10σ) and a corresponding surface brightness of $\mu_{g'} \sim 27.7$ mag arcsec^{-2} (2σ). The NGVS will completely supersede all previous optical studies of this uniquely important system, and, by leveraging the vast amount of data available at other wavelengths, will allow us to address a wide range of fundamental astrophysical questions, including: the faint-end shape of the luminosity function, the characterization of galaxy scaling relations over a factor 10^7 in mass, the cluster/intracluster medium/galaxy connection, and the fossil record of star formation and chemical enrichment in dense environments. Numerous ancillary projects — from a survey of the Galactic halo to a cosmic shear measurement of the matter power spectrum on large scales — will also be enabled.

Not only will the NGVS be the definitive study of baryonic substructures in a low-z cluster environment for years to come, but it will yield the benchmark observational database against which the next generation of hierarchical formation models will be tested. As such, it will be a lasting legacy of CFHT.

Proprietary period:

To enhance its legacy value, the NGVS will adopt the following policies regarding data release:

- All participating Agencies will have immediate access, through the Canadian Astronomy Data Centre (CADC), to the raw images, as well as to the pre-processed and stacked images and source catalogues produced by *Elixir*, *MegaPipe* and *Terapix*.
- The international community will have access to the raw data one year after acquisition, and to *Elixir, MegaPipe* and *Terapix* data products one year after the completion of the survey (2013).
- All processed data created using pipelines built within the collaboration will be released internationally once the primary objectives of the survey have been achieved by the team, and no later than two years after the completion of the survey.
- To enhance the synergistic opportunities of the survey, throughout the duration of the NGVS, the team will remain open to collaborations and sharing of proprietary data with other consortia.

Total Number of Hours Requested: 771

Hours Per Agency: Canada 325 France 325 Hawaii 121

Co-Investigators:

Chantal Balkowski	Observatoire de Paris, GEPI	France
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John Blakeslee	NRC/HIA	Canada
Samuel Boissier	Laboratoire d'Astrophysique de Marseille	France
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Christine Wilson	McMaster University	Canada

Instrument: MegaPrime **Filters: $u^*g'r'i'z'$**

Target Coordinates and Exposure Time Distribution (Hours/Semester/Agency):

Semester / Target	2009A	2010A	2011A	2012A
Virgo cluster $12h\ 09m \leq \alpha \leq 12h\ 51m$ $4° 40' \leq \delta \leq 17° 45'$	82h (Canada) 82h (France) 31h (Hawaii)	81h (Canada) 81h (France) 30h (Hawaii)	81h (Canada) 81h (France) 30h (Hawaii)	81h (Canada) 81h (France) 30h (Hawaii)

Scientific Justification

S.1 The Future of Cosmological Surveys: The Low Redshift Universe.

Understanding the growth of structure in the universe is one of the primary goals of modern astrophysics. In the past decade, observations of the cosmic microwave background, baryon acoustic oscillations, cosmic shear, high-z supernovae, galaxies, quasars and clusters, have led to significant progress towards an understanding of hierarchical structure formation within a cold dark matter (CDM) dominated universe. ΛCDM cosmological parameters have now been measured with remarkable precision, leading to commensurate advances in our understanding of the initial conditions that governed the growth of structures on all scales. These achievements have been mirrored by advances in the speed and precision of numerical methods used to simulate the hierarchical formation of structures over wide ranges in mass and radius[e.g.,109]. But while there is now apparent agreement, on the scales of galaxies and smaller, amongst simulations containing dark matter only — with convergence typically achieved down to scales of $R \sim 0.003R_{200}$ and good consistency found using different codes with different initial conditions[e.g.,91,29] — the situation is far more complicated when baryons are added to the simulations[e.g.,44,68,90].

Further progress towards understanding the assembly of the Baryonic Sub-Structures (BSSs) we see locally hinges on the treatment of astrophysical processes that are poorly understood at the present time: e.g., gas dynamics, radiative cooling, star formation, and stellar/AGN feedback. This realization has spawned a renewed interest in the detailed properties of galaxies in the local universe, as such systems are the obvious testbeds for simulations that attempt to explain the bewildering array of BSSs. *In short, studies of the high-redshift universe can give us an integrated, statistical picture of galaxy evolution over cosmic time, but it is only through detailed studies of the local volume that we can hope to understand the role of gas dynamics, cooling, star formation and feedback in the hierarchical assembly of baryonic substructures.*

S.2 Virgo: A Unique Astrophysical Environment

At a distance of 16.5 Mpc[81] and with a gravitating mass of $\mathcal{M}_{200} = 4.2\times10^{14}\ \mathcal{M}_\odot$[78], the Virgo Cluster is the dominant mass concentration in the local universe, the centre of the Local Supercluster, and the largest concentration of galaxies within ~ 35 Mpc. With thousands of member galaxies lying at a nearly common distance and spanning virtually all known morphological types, it has historically played a key role in studies of how galaxies form and evolve in dense environments. It is, without question, the most thoroughly studied cluster of galaxies in the universe, and remains the obvious first target for a systematic survey of BSSs in the low-z universe.

Yet the Virgo Cluster survey that serves as the standard reference in the optical is now nearly a quarter century old. Beginning in the late 1970s, Binggeli, Sandage & Tammann capitalized on the wide-field (1.5°×1.5°) imaging capabilities of the 2.5m du Pont telescope at LCO to carry out photographic imaging of Virgo down to an extended-source completeness limit of $B_{\rm lim}\approx18$ mag (≈22 for point sources). Their resultant Virgo Cluster Catalog (VCC[9]) identified and classified ≈2100 certain or possible cluster members over an area of $\simeq 140$ deg^2. The SDSS (which, admittedly, has the distinct advantage of multi-band coverage) has not significantly improved upon the VCC point- and extended-source detection limits (for the SDSS[25]: g~22.2, $\mu_{g,effective}$~25.5 mag arcsec^{-2}; for the VCC: B~22 mag, $\mu_{B,effective}$~25.3) due to its relatively poor image quality (~1.4″ FWHM), modest telescope aperture (2.5m) and short exposure times (54s).

The VCC had an immediate and lasting impact on a remarkably wide range of astrophysical questions (e.g., the form of the galaxy luminosity function, the photometric and structural properties of galaxies, the abundance of high- and low-surface brightness galaxies, the extragalactic distance scale, the nature of galactic nuclei, the galaxy-ICM connection, the morphology-density relation, the dynamics and virialization of galaxy clusters, and the distribution of dark matter). For the past 23 years, the VCC has served as the departure point for innumerable, multi-wavelength followup studies. With more than 2000 citations to the VCC to date (a number that continues to grow steadily with time), it remains the best existing optical survey of the most thoroughly studied cluster in the universe. Yet the VCC is now hopelessly out of date by modern standards, and the large number of planned or ongoing surveys of the Virgo Cluster at X-ray, UV, infrared, submm and radio wavelengths (see §T.8 and Fig. 1) are now, ironically, limited by the lack of deep, high-quality *optical* data for this benchmark cluster.

S.3 Beyond the VCC: The Next Generation Virgo Cluster Survey (NGVS)

We propose an ambitious MegaPrime survey that will not only supersede the VCC, but will represent the state-of-the-art optical survey of BSSs in a z~0 environment for years to come — the *Next Generation*

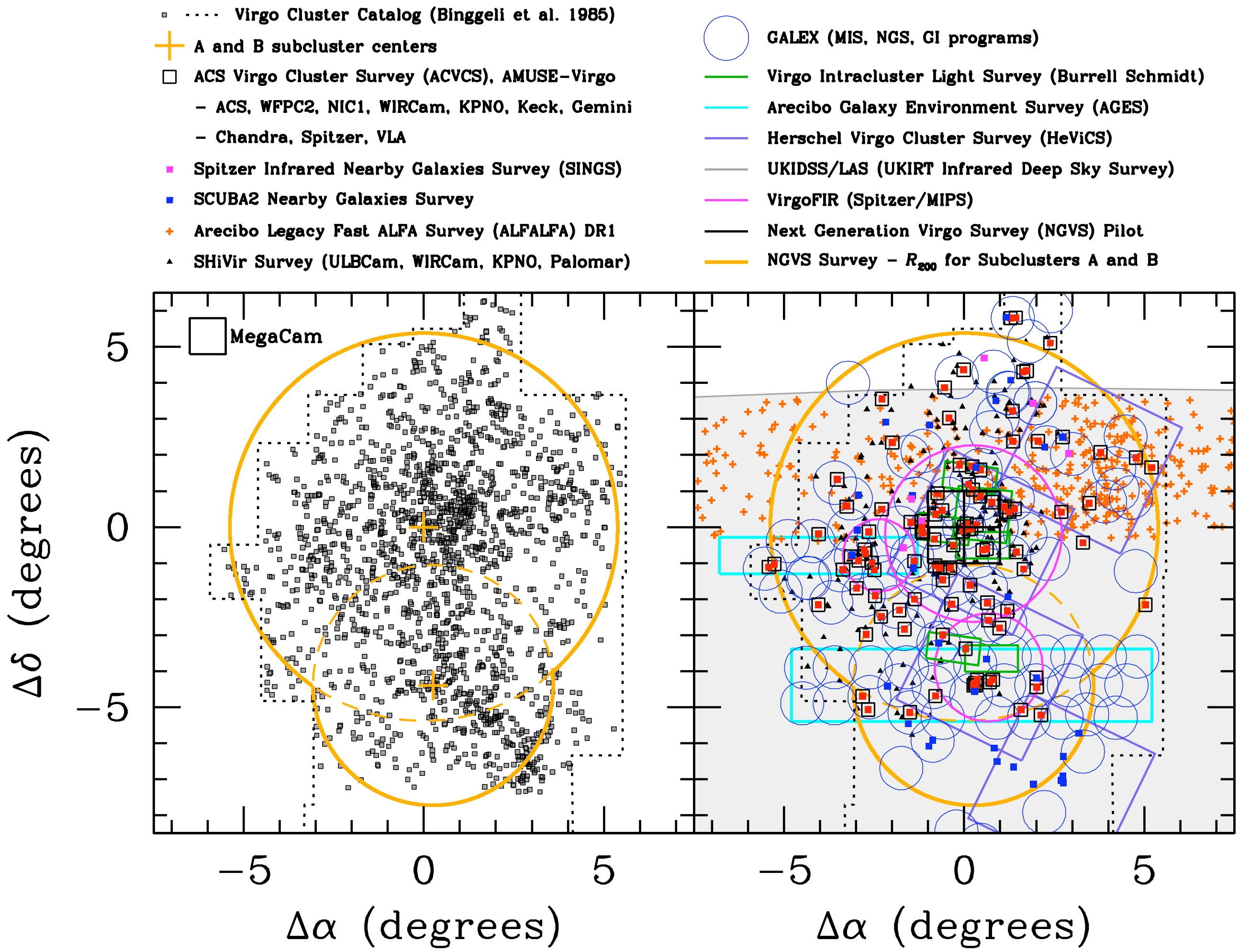

Figure 1. (*Left*) Outline of the NGVS (in heavy orange) compared to that of the Virgo Cluster Catalog (VCC; dotted lines). The two orange crosses indicate the X-ray centres of the *A* and *B* subclusters; the dashed orange curves show the virial radii of the two subclusters. The 1726 black squares show confirmed and probable cluster members (down to $B \sim 20$ mag) from the VCC with $\delta > 5°$. (*Right)* Synergy between the NGVS and ongoing or approved surveys of the Virgo Cluster region (at primarily non-optical wavelengths). See §T.8 and §D.3 for details.

Virgo Cluster Survey (NGVS). By fully imaging the region inside the virial radii of Virgo's two main substructures (a total area of 104 deg^2, Fig. 1) to depths of g'~25.7 AB mag (10σ detection limit for point-sources) and μ_g~27.7 AB mag arcsec^{-2} (2σ detection for extended sources) in all five SDSS filters, we shall produce the definitive dataset with which to compare and test models of hierarchical structure formation. Compared to the VCC, the NGVS represents dramatic improvements in depth (~100× in luminosity for point sources), surface brightness (~40×), angular resolution (~6× in encircled energy), completeness, wavelength coverage (five bands versus one for the VCC), and synergistic opportunities with the many planned or ongoing Virgo surveys at other wavelengths (see §T.8). As was the case for the VCC, targeted and survey spectroscopic campaigns of the NGVS will inevitably follow; indeed, several such projects (including multi-object spectroscopy aimed at verifying membership selection criteria and characterizing new sources) will be carried out by the NGVS team using the many 4-8m-class telescopes to which we have access.

In the remainder of this proposal, we shall briefly outline some of the immediate scientific rewards expected from the NGVS. However, the legacy value of this dataset will go well beyond these specific topics: true to the spirit of surveys, the NGVS will be of broad interest to the worldwide astronomy community for years to come, likely enabling many unanticipated returns.

❒ S.3.1 The "Missing Satellite" Problem and the Faint-End of the Luminosity Function.

In the favored ΛCDM paradigm for structure formation, large galaxies arise from the merger and accretion of many smaller subsystems. Perhaps the most striking failure of this now well-developed model is the apparent discrepancy between the expected and observed numbers of dwarf galaxies: i.e., the so-called "missing satellite problem"[66,85]. From a theoretical perspective, the problem is insidious since there are many possibilities for altering the low-mass end of the ΛCDM mass function, including modifying the power spectrum on small scales, changing the properties of the dark matter particles, invoking the late decay of a non-relativistic particle, or through a wide variety of "baryonic" processes that modify the shape of the luminosity function (LF) by ensuring that low-mass ΛCDM haloes remain "dark" as a result of inhibited gas inflow and cooling (e.g., through stellar and galactic winds, AGN or SN feedback, reionization, §S.3.2).

Although there has been tremendous progress in our understanding of the Local Group LF (thanks mainly to SDSS and wide-field surveys of Andromeda[e.g., 6]), the faint end of the LF remains highly uncertain owing to selection effects and the fundamentally limited sample size available in the Local Group. Nevertheless, the ever-increasing number of faint ($M_B \gtrsim -10$ mag), compact (r_e~150 pc) and low surface brightness (LSB; $\mu_{B,0} \gtrsim 25$ mag arcsec^{-2}) Local Group galaxies discovered in recent years leaves no doubt that the LF is considerably steeper than once believed. Our best hope for a *definitive* measurement of the LF — based on complete and homogeneous data for many thousands of galaxies within a common environment — is through a deep survey of the Virgo Cluster. Indeed, this was a primary goal of the VCC, with Sandage et al. (1985) finding $\Phi(M) \propto 10^{0.4(M^{*}-M)(\alpha+1)}$ and $\alpha \approx -1.3$ down to their rather bright completeness limit of $B_{\rm lim} \approx 18$ mag ($M_B \approx -13$ mag or $\mathscr{M}_b \sim 10^8 \mathscr{M}_\odot$).

Although Virgo has been the target of numerous subsequent investigations of the faint-end of the LF, the agreement amongst these studies has generally been poor (see Fig. 2). Values range from $\alpha \lesssim -1.3$ to $\alpha \sim -2.2$, although virtually all studies agree that the Sandage et al. (1985) LF, by virtue of the VCC's relatively bright surface brightness detection limit of $<\mu_{B,e}> \sim 25.3$ mag arcsec^{-2}, is actually a *lower bound* on the true LF[e.g.,57,95,102]: indeed, the ongoing intracluster light survey of Mihos et al. (ICLVS)[84] suggests that there may be a large population of LSB objects that are not catalogued in the VCC[57,102]. The NGVS will resolve these discrepancies with ease thanks to its greatly improved point-source and surface brightness detection limits, the availability of precise photometric redshifts (which will allow the overwhelming majority of compact background galaxies to be identified and excluded, §T.6), its superior image quality (which will allow the identification of cluster members through the use of photometric and structural scaling relations; see §S.3.4 and Fig. 3), and its multi-wavelength coverage. To put the depth and sensitivity of the NGVS into perspective, if placed at the distance of Virgo, not only we would be able to detect nearly all of the classical dwarf spheroidal companions of the Milky Way, but *all* of the six most recently discovered satellites of M31[6] (Fig. 3). To illustrate our sensitivity to differences in the value of the faint-end slope, the number of galaxies (from B =17 to 27 mag) in the NGVS is expected to be $N \sim 1.6 \times 10^4$, 2.1×10^5 and 3.5×10^6 for $\alpha = -1.3$, -1.7 and -2.0, respectively.

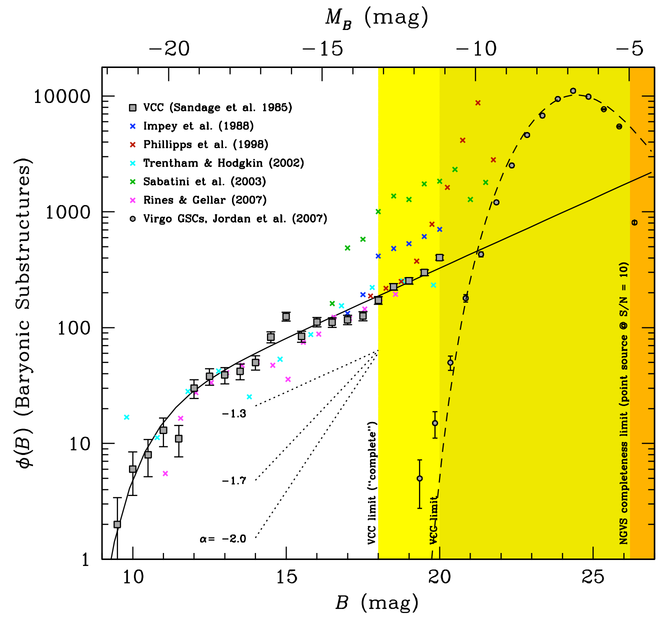

Figure 2. The Virgo Cluster LF from the VCC[105] compared to more recent measurements. The solid curve is the best-fit Schechter function of Sandage et al. 1985 ($\alpha = -1.3$). There are clear discrepancies in the LF measurements for $M_B \gtrsim 16.5$, with slopes ranging from ≈ -1.3 to ≈ -2.2 [95]. [Note that $(B-g') \sim 0.55$ for old, intermediate-Z stellar populations]. The value of ≈ -1.3 [98] is a *firm lower limit* on the LF slope for $-19 \lesssim M_B \lesssim -12$ as it is based entirely on SDSS radial velocities, and may thus exclude low surface brightness members. Also shown is the expected LF of Globular Star Clusters (GSCs) in Virgo; the dashed curve shows an "evolved Schechter function" that includes the effects of stellar evaporation at the faint end of the LF. By going significantly deeper than the VCC, the NGVS will yield a nearly complete census of $N \approx 6.4 \times 10^4$ GSCs ($10^4 \lesssim \mathscr{M}_b/\mathscr{M}_\odot \lesssim 10^7$) in Virgo and many thousands of galaxies in the range $10^{4.5} \lesssim \mathscr{M}_b/\mathscr{M}_\odot \lesssim 10^{11.5}$.

❒ S.3.2 Cosmic Star Formation and Chemical Enrichment: The Fossil Record at $z \approx 0$

A parallel effort in the search for "missing satellites" has focused on "dark galaxies" — gas rich, low-mass systems that may elude optical surveys due to strongly inhibited star formation (i.e., HI mass to *B*-band luminosity $\mathcal{M}_{HI}/L_B > 5\ \mathcal{M}_{\odot}/L_{\odot}$, compared to ~ 0.1−1.0 $\mathcal{M}_{\odot}/L_{\odot}$ for HI-selected LSB galaxies). Although unsuccessful [e.g.,30,31], current searches for dark galaxies in the form of isolated HI clouds have only been sensitive to rather large HI masses ($\mathcal{M}_{HI} > 9{\times}10^8\ \mathcal{M}_{\odot}$ at the distance of Virgo[121]) and been further hampered by the lack of a deep, homogeneous catalogue for optical cross-identification, requiring dedicated follow-ups of every potentially interesting HI detection.

The NGVS, in combination with ALFALFA and AGES — two deep HI surveys being carried out at Arecibo[1,42] (see Fig. 1) — should break this field open. ALFALFA will detect objects down to $3{\times}10^7\mathcal{M}_{\odot}$ throughout the Virgo Cluster[65] while AGES will go almost a magnitude deeper ($5{\times}10^6\ \mathcal{M}_{\odot}$) in two selected regions totaling 25 deg^2. With a surface brightness detection limit of μ_g = 27.7 mag arcsec^{-2}, the NGVS will allow the immediate identification of BSS with $\mathcal{M}_{HI}/L_B$ as high as ~1000 $\mathcal{M}_{\odot}/L_{\odot}$ for the lowest mass HI systems.

By combining the NGVS and HI data it will also be possible to measure directly the amount of stars a galaxy can form, as a function of total baryonic mass, luminosity, morphology and environment, and probe whether a limit exists above which a subhalo becomes unstable to star formation[e.g.,111,119]. Both are critical issues for a realistic treatment of star formation within cosmological simulations of galaxy evolution.

Finally, a clear synergy exists between the NGVS and UV (GALEX[12]), near-IR (UKIDSS), far-IR (Herschel), and submm (SCUBA2) surveys of Virgo, all of which are either completed or in the pipeline (Fig. 1). By providing information on the local stellar spectral energy distribution (SED), the NGVS will yield the high-quality optical data needed to obtain *complete* SEDs and produce extinction-corrected 2D maps of the stellar populations and ongoing star formation in galaxies spanning an enormous range in mass and local environment. With a completion date of 2012, the NGVS will also serve as an timely pathfinder survey for pointed observations with JWST and ALMA.

❒ S.3.3 The Cluster-ICM-Galaxy Connection.

A fundamental prediction made by ΛCDM simulations of structure formation is an abundance of LSB intracluster tidal debris from disrupted systems, and a ubiquity of diffuse stellar structures, both surrounding galaxies (e.g., haloes and thick disks) and permeating intracluster space. *N*-body and hydrodynamical simulations make specific predictions regarding the dynamics, mass, spatial distribution, age, and metallicity of such features[e.g.,15,108]. Thanks to its depth and multi-wavelength nature, the NGVS will enable quantitative tests of these simulations by providing direct observations of the stellar population content and spatial structure (in relation to the cluster potential well, as traced by the X-ray gas) of both the unresolved and discrete tracers of the hierarchical assembly processes.

With a very low surface brightness limit of μ_g = 27.7 mag arcsec^2 (2σ detection above the sky; μ_g = 28.5 at 1σ), and the precise flat fielding enabled by repeated observations over large areas of the sky — the spatial structure and integrated population content of the diffuse stellar component can be traced continuously from galaxy[27] to cluster[84] scales. Likewise, by reaching a completeness limit encompassing 90% of the LF of Globular Star Clusters (GSCs) (§T.4) and carefully accounting for background/foreground contamination (§T.6), the spatial distribution of GSCs (Pop II tracers of galactic haloes) can be mapped from individual galaxy subhaloes out to cluster-wide scales. At the bright end of the GSC LF, the NGVS will detect Ultra Compact Dwarf galaxies[52], currently believed to be the heavily stripped remnants of nucleated dwarf galaxies.

❒ S.3.4 The Manifold of Baryonic Substructures: Scaling Relations over Seven Orders of Magnitude

While the present-day LF provides strong constraints on the global, *macroscopic* processes that governed the accretion and cooling of gas in dark matter haloes, it is the detailed photometric, structural and dynamical scaling relations of individual BSSs that tell us about how these processes unfolded on galaxy scales. Historically, this field has a rich tradition of yielding important — and often unexpected — insights to the formation and evolution of galaxies[e.g.,24,32,33,39114]. Indeed, a number of recent, independent observational programmes seem to be leading to a paradigm shift in our understanding of the photometric, structural and dynamical properties of BSSs, with mounting evidence for unexpected commonalities among BSSs spanning an enormous range in mass[e.g.,23,35,37,47,123] (see Fig. 3).

The NGVS will enable a quantum leap forward in the characterization of BSS scaling relations in the low-redshift universe. It will yield accurate, homogeneous and complete photometric and structural information for thousands (and, depending on the form of the Virgo LF, perhaps tens or even hundreds of thousands) of BSSs of virtually all known morphological types and spanning a factor of ~10^7 in baryonic mass (from supergiant ellipticals with $\mathcal{M}_b \approx 10^{11.5}\ \mathcal{M}_{\odot}$ to LSB galaxies and GSCs with $\approx 10^{4.5}\ \mathcal{M}_{\odot}$). Data products from the NGVS will include integrated luminosities, colours (eight independent indices) and stellar masses (from $u^*g'r'i'z'$ SED fitting supplemented with UV and NIR measurements), surface brightness and colour profiles (with a physical resolution of ~100 pc), scale radii, and multi-component photometric decompositions in both 1D and 2D. Ongoing (*SHiVir, Atlas3D, ACSVCSpec,* see §T.8) and planned (e.g., §S.3.7) spectroscopic surveys using longslit and IFU spectrographs on a variety of 4-8m-class telescopes will yield dynamical information for ~10^3 of the brighter galaxies. Taken together, the NGVS will provide the definitive $z \approx 0$ dataset for testing and refining the next generation of numerical simulations. These models are now reaching the levels of speed and sophistication needed to incorporate the many physical processes that are thought to be responsible for the scaling relations of present-day BSSs: e.g., gas accretion and cooling, thermal evaporation, adiabatic contraction, gas inflow via compressive tidal forces, accretions and merging, dynamical friction, star formation, feedback in the form of AGN flaring and central starbursts, ram-pressure stripping, and harassment[e.g.,18,26,28,56,75,89,109,].

❒ S.3.5 Environment and Galaxy Evolution.

The effects of large-scale environment on galaxy evolution include differences in the mass accretion history[e.g.,74], starvation/strangulation [69,76], galaxy interactions[85] and ram pressure stripping of cold gas[e.g.,48,92]. Within a cosmological context, quantifying environmental effects is essential if we are to understand the rapid transformation from blue-cloud to red-sequence galaxies and the sharp decline in star formation over the past 5-10 Gyr[e.g.,2,4,40,41,116].

Attempts to distinguish between different environmental effects based on integrated stellar populations alone have met with limited success[e.g.,3,50,97]. However, such a distinction becomes possible when the detailed galaxy morphology is considered together with the spatial distribution of the stellar populations and HI gas[e.g.,13,64,88,117].

The Virgo Cluster, because of its proximity, complex structure, and the wealth of existing information on all phases of its ICM (§T.8), affords us a unique opportunity to study galaxy evolution within a cluster environment in exquisite detail. The NGVS will enable such studies by offering two key advantages over existing optical surveys — depth and image quality.

Both attributes will allow us to study galaxies over the full extent of the luminosity function, making it possible to uncover the remnants of environment-driven processes that truncate star formation and cause a galaxy to fade. Virgo is the only rich cluster near enough to enable the detection of dwarf galaxies throughout its potential well. This ability to trace the faintest systems from the cluster core to its periphery is of particular importance: because of their low binding energy, the faintest galaxies are the ones most affected by environment[e.g.2]. With the NGVS, stellar systems can be detected down to GSC scales, and both high- and low-mass galaxies can be studied in exceptional detail down to a resolution element of ≈0.02 kpc^2.

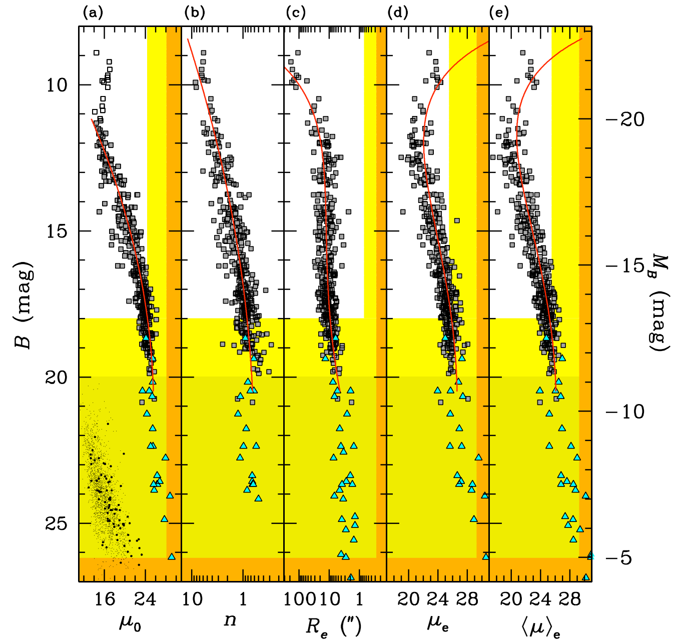

Figure 3. Photometric and structural scaling relations for bright early-type galaxies in the Virgo Cluster. The panels show the relationship between *(a)* *B*-band magnitude and central surface brightness, *(b)* Sersic index, *(c)* effective radius, *(d)* surface brightness measured at R_e, and *(e)* average surface brightness within R_e. Grey symbols show best-fit parameters using a Sersic model parameterizations for bright VCC galaxies[e.g.,35,37,110]. Open symbols in *panel (a)* indicate so-called “core” or “deficit” galaxies whose central brightness profiles are thought to have been heavily modified by the evolution of super-massive black hole binaries. The smooth red curves are scaling relations from Côté et al. (2008). For comparison, the cyan triangles show the location of faint dwarf satellites of the Milky Way and M31[6], while Galactic GSCs, as they would appear at the distance of Virgo, are shown as small black squares in the first panel (although the GSCs are, of course, unresolved). Completeness limits in magnitude, surface brightness and effective radius for the VCC[9] are shown in bright and dark yellow; those of the NGVS are shown in orange. The dramatic improvements of the NGVS in depth (~100×), surface brightness sensitivity (~40×), image quality (~6×) and SED coverage (5×) will open an entirely new window on Virgo, the rich cluster nearest to the Milky Way.

In addition, the excellent NGVS image quality (0.6″ seeing in i') will make it possible to use surface brightness fluctuations (SBF[e.g.,81,112]) to measure distances to ~150 of the brightest (E, S0, Sa, dE) galaxies, and hence recover the full, three-dimensional structure of Virgo. The NGVS multi-wavelength coverage will ensure accurate calibration of the SBF method for nearly all galaxy types, with uncertainties of ~1 Mpc per galaxy, sufficient to distinguish populations located in the core from those in the outskirts, and to identify projected structures. Thus, it will be possible to study how the galaxy populations correlate with *local*, rather than *projected,* environment.

The ensuing dataset — sampling environments from elliptical-dominated clumps to gas-poor spiral-rich regions, and covering a wide range in ICM densities — will enable a detailed analysis of environmental effects on galaxy evolution. For instance, a spatial distribution of the faintest, red-sequence galaxies that correlates with cluster-centre distance would indicate that star formation is sensitive to the global cluster potential[e.g.,3], while a correlation with ICM density would be strong evidence for ram-pressure stripping[e.g.,86,97,117]. In individual galaxies, the presence of tidal features and the spatial distribution of star forming regions (e.g., the presence of a central starburst as opposed to low levels of widely distributed star formation) are sensitive to processes such as galaxy interaction, strangulation and starvation.

❐ S.3.6 The Core Structure of Galaxies: from Nuclear Star Clusters to Supermassive Black Holes.

The importance of understanding the core structure of galaxies has been emphasized in recent years, starting with the discovery of numerous scaling relations linking supermassive black holes (SBHs) to global galactic properties, and continuing with a re-evaluation of the role of AGN feedback in driving galaxy evolution. An even more recent result is the discovery that the vast majority of late- *and* early-type galaxies fainter than $M_B \sim -20$ mag (down to the limit of existing samples: $M_B \sim -15$ mag) harbour structurally-distinct central stellar components (sometimes referred to as nuclear star clusters, NSC[11,22]). NSCs are most likely to have formed as a consequence of gas inflows, perhaps triggered by accretion events[22,36,83,101,118]. NSCs are not present in the brightest galaxies, which are known to harbour central SBHs, but interestingly, NSCs and SBHs comprise roughly the same fraction, ~ 0.2%, of the total galaxy mass[36,101,120], tantalizing evidence for commonalities in their formation mechanisms [79].

If the scaling relations defined by NSCs in Virgo galaxies brighter than $B_T \sim 16$ mag continue to fainter magnitudes, then the NGVS (thanks to its depth and image quality; §T.3 and §T.4) will allow us to extend the study of NSCs to galaxies as faint as $B_T \sim 20$ mag. This unique dataset will directly probe the efficiency of gas inflow and nuclear star formation in galaxies spanning a factor of ~10,000 in luminosity, as a function of morphological type, environment, ISM pressure (from ROSAT), and HI content (from AGES[1]). Furthermore, it will be a key foundation for follow-up spectroscopy and X-ray imaging to identify potential dwarf AGN activity associated with nucleation.

❐ S.3.7 The Structure of Dark Matter Haloes and the Form of the Baryonic Velocity Ellipsoid.

The structure of dark matter haloes in rich clusters continues to be a subject of intense debate, with much attention focused on clusters at $z \sim 0.2$−0.4 where multiple observational constraints (e.g., integrated-light spectroscopy of the central galaxy, X-ray profiles, strong and weak lensing features, SZ measurements) can be used to infer the gravitating mass profile over large spatial scales. However, such studies often arrive at nearly orthogonal conclusions, with large uncertainties arising from the unknown shape of the velocity ellipsoid of the baryonic tracers used to probe the mass profile on small scales[103,104,115]. This issue is of fundamental importance since an unambiguous separation of the dark matter and baryonic components is needed to understand the process of adiabatic contraction and the effect of the condensing baryons on the form of the dark matter halo[e.g.,44].

The Virgo Cluster offers a unique opportunity to address this fundamental issue. While detailed dynamical analyses of Virgo's *A* and *B* subclusters have already been carried out[19,20,78,80] by combining photometry and long-slit spectroscopy for the central ellipticals (M87 and M49), radial velocity measurements for GSCs and dwarf galaxies, and large-scale X-ray mass profiles from ROSAT, the NGVS will supersede past measurements by uncovering $\gtrsim$20,000 GSCs and ~2000 dwarfs (for a conservative assumption of $\alpha = -1.3$) bright enough to allow radial velocity measurements with multi-object spectrographs on the 8m-class telescopes to which our team has access (Magellan, MMT, VLT, Keck, Gemini and Subaru). Radial velocity measurements for even a fraction of these systems will yield discrete velocity samples large enough[82] to identify the region over which the cluster has achieved virialization, and allow an unprecedented *simultaneous* measurement of the mass profile and the velocity ellipsoid of the baryonic tracers within the cores of these subclusters.

■ S.4 Background Science from the NGVS.

The NGVS will have the *deepest and widest contiguous coverage* of any optical medium-deep survey to date[127]. At a Galactic latitude of b=75°, the NGVS is relatively unaffected by galactic extinction and contamination from foreground stars, and is naturally conducive to studies of background structures.

❐ **S.4.1 Cosmic Shear.** Cosmic shear — the small, but coherent alignment in the shape of distant sources produced by intervening structures — is a unique probe of the distribution of dark matter and the properties of dark energy. As such, it was the main science driver of the Wide component of the CFHT Legacy Survey (CFHTLS), which imaged four fields, totaling 170 deg^2, at depths comparable to the ones proposed here. The NGVS has, however, one distinct advantage over the CFHTLS-Wide: it has *the largest contiguous field* imaged to this depth and with this image quality. For comparison, the largest of the CFHTLS-Wide fields is 64 deg^2, almost a factor two smaller than the NGVS. The NGVS will therefore yield one of the few high-quality measurements of the matter power spectrum on scales beyond 8°, improving constraints on the equation of state, w, by ~ 30% over the CFHTLS.

❐ **S.4.2 The Effect of Tidal Field on Galaxy Shapes.** A second issue which the NGVS will be uniquely able to address is the determination of the intrinsic alignment (IA) of galaxies within the tidal field of a cluster (Virgo in our case). The measurement is of interest in its own right, but it is also needed to realize the full potential of cosmic shear measurements[53]. Studies based on bright ($M_r < -19$) galaxies from the SDSS and 2dF[7,54,72], indicate that gravitational lensing/intrinsic ellipticity correlations are capable of producing contamination in the power spectrum, and potentially introduce biases in the cosmological parameters that are derived from it.

Cosmic shear studies using future synoptic surveys (SNAP, DUNE, DES, LSST) will reach limiting magnitudes as faint as $M_r \sim -15$, and will be affected by the IA of galaxies far fainter than can be probed by the SDSS. The NGVS offers a unique opportunity to study the IA to these limits within a nearby cluster environment. The enormous number of spatially-resolved galaxies (§S.3.1 and Fig. 2 and 3) — much too close to be distorted by lensing — will allow a measurement of the absolute IA signal to 1% at 1σ or better.

❐**S.4.3 Galaxy Clusters at $z < 1$.** With a surface density of ~ 20 clusters deg^{-2} [93], the NGVS will detect ~ 2000 galaxy clusters with redshifts between 0.1 and 1.0. While this number is smaller than what is expected from the shallower, but wider, Red Cluster Survey 2[122] (RCS2), the NGVS offers two main advantages for cluster studies. First, for the most massive clusters (σ ~ 700-1200 km s^{-1}), the NGVS depth and spatial resolution will enable *weak lensing measurements* (an impossibility using RCS2) out to $z \sim 0.5$[38]. Second, between 70 and 300 *strong lensing structures* will be discovered, spanning the full range from massive galaxies to rich clusters. The combination of NGVS and CFHTLS-Wide data will lead to a unique catalogue of 200–800 strong lenses[16] which will constitute an invaluable database for followup studies of the mass density profiles in galaxy groups and clusters, as well as for the study of highly magnified, star-forming galaxies[e.g.,43].

■ S.5 Foreground Science from the NGVS.

❐ **S.5.1 The Milky Way Halo.** The NGVS will sample ≈ 100 deg^2 of the stellar halo of the Milky Way, identifying halo stars well below the main-sequence turnoff. The field location is particularly interesting, since it lies squarely in the direction of the "Virgo Overdensity" within the so-called "Field of Streams"[6]. The Virgo Overdensity is the largest clump of tidal debris ever detected in the outer halo [61,73]. By combining the NGVS data with other surveys — particularly the proposed CHFT Large Proposal targeting M31/M33 (P.I. = McConnachie) that will probe the Galactic halo on the opposite side of the sky — it will be possible to compare the line-of-sight distribution of stars along different halo sightlines with Galactic halo models[e.g.,99], and to measure directly the shape and symmetry of the stellar halo.

❐ **S.5.2 The Kuiper Belt.** The outer solar system offers a further demonstration of the broad appeal and multi-disciplinary nature of the NGVS. At an ecliptic latitude of β=14°, ~90 Kuiper Belt Objects (KBOs) as faint as r'=24.3 (S/N=10) and moving as slowly as 1″/hour will leave visible traces in our 7 back-to-back r' exposures (§T.4 and Table 2). Of these KBOs, ~30 and ~10 are expected to be in a 3:2 and 2:1 resonance with Neptune, respectively, twice the number discovered in the Canada–France Ecliptic Plane Survey (CFEPS[58]). These KBOs are of particular interest, since their relative numbers, and the ratio of trailing to leading asymmetric 2:1 librators, can uniquely determine Neptune's migration rate and, by inference, constrain the role of planetary migration in the evolution of planetary systems [e.g.,70,87]. Although these topics are beyond the core science goals of the NGVS team, a list of KBO coordinates will be released to the *international* community through the NGVS website, to allow interested parties to pursue dedicated follow-up observations and secure the KBO orbits.

Table 1: NGVS Survey Region and the Properties of the A and B Subclusters						
Subcluster	Central Galaxy	Central RA α(2000)	Central Dec δ(2000)	Distance (Mpc)	Mass ($\mathcal{M}_{\odot}$)	Virial Radius (R_{200})
A	M87	12h 30m 49s	12° 23′ 28″	16.7	4.2×10^{14}	5.38° = 1.55 Mpc
B	M49	12h 29m 47s	08° 00′ 02″	16.4	1.0×10^{14}	3.33° = 0.96 Mpc

Technical Justification

An NGVS pilot programme targeting 4 deg^2 was approved as the top Canadian proposal for 2008A, and will be executed in PI mode. The data will be fully reduced and analyzed well before the 2009A start of the NGVS, and used to refine, if necessary, the observing strategy described below.

T.1 Field of View.

The NGVS will cover the 104 deg^2 region enclosed within the virial radii of Virgo's *A* and *B* subclusters (Fig. 1, Table 1); the central 4 deg^2 will be surveyed by our pilot project. North of 5°, there is excellent spatial overlap between the VCC and the NGVS. In particular, the NGVS includes the M86 subcluster, located to the West of M87 (d~17.6 Mpc), the background *M*-cloud to the North-East (d~30 Mpc) and the infalling *W'* and *W* clouds to the South-West (d~23 Mpc). The NGVS excludes the "Southern Extension" at δ<5°, an elongated spur in the foreground of the main cluster.

Background and foreground contamination (§T.6) will be assessed using 4 control fields offset by 15° ($\approx 3R_{200}$) on either side, from the top/bottom edge of the NGVS main field, along lines of constant galactic latitude.

T.2 Filter Selection.

A panchromatic view is an absolute prerequisite to our achieving the science goals of this proposal. The long wavelength baseline (u^* to z') is essential to decouple age and metallicity effects when comparing the data against stellar population models, with u^* playing a crucial role in revealing recent or ongoing star formation[127] (Fig. 4). Moreover, u^* is crucial for distinguishing background galaxies from cluster members (Fig. 4 and §T.6), and for a seamless comparison of Virgo's LF, star formation properties and colour-magnitude diagrams to those of more distant clusters. Similarly, stellar mass measurements hinge critically on the redder passbands — z' in particular. All five filters are needed for the measurement of photometric redshifts, which are needed to assess background contamination, as well as for studies of high-z clusters and cosmic shear.

T.3 Seeing Conditions.

Seeing of order 1″ is adequate for our purposes, although better seeing (~0.6″) is required in one band to: (1) enable the measurement of SBF distances[81]; (2) separate the largest UCDs (which have half-light radii r_h $\lesssim$0.25 arcsec[52]) from GSCs (r_h ~ 0.03 arcsec[60]) by marginally resolving them; and (3) facilitate the detection of stellar nuclei against galaxy cores in intermediate luminosity systems[22]. The mode of the seeing measured across MegaCam frames between 2003 and 2006 is 1.0″ (u^*), 0.8″ ($g'r'$) and 0.6″ ($i'z'$) [124]. Requesting 0.6″ seeing in i' (the band of choice for SBF) lessens our scheduling constraints, given the shorter integration times compared to z' (§T.4), and routinely better seeing conditions compared to u^*, g' and r'. In u^*, a seeing of 1.1″ is acceptable if required for efficient scheduling. All exposures must be taken at an airmass ≤1.5, both to keep the exposure times within acceptable limits, and because of seeing degradation at larger airmasses[124].

T.4 Exposure Times.

Exposure times are driven by our need to obtain a deep, complete LF for BSSs in Virgo, including both compact (unresolved) and LSB systems. While the photometric/structural properties of the faintest BSSs are poorly known at this time (indeed, this is one of the prime motivations for the NGVS) we can make some reasonable assumptions based on the properties of the faintest Local Group galaxies. [As Fig. 3 shows, LSB systems in M31 and Milky Way appear to fall along the extrapolations of the scaling relations defined the brighter VCC galaxies.] To detect the nine "classical" dSphs associated with the Milky Way, as well as all known satellites of M31 (i.e., And I–XV), we require a depth of $g' = 24.7$ ($M_B \approx -6$). At the distance of Virgo, these objects would have $r_e \leq 4''$ (equivalent to FWHM ≤ 9.5″). To reach an integrated S/N>2 within r_e, we require the exposure times recorded in Table 3 under the "Long Exposures" heading (the calculations assume an average airmass of 1.2). For unresolved BSSs, such as GSCS and the most compact UCDs, these depths will allow the detection (at S/N=10)[1] of the brightest 90% of the LF, which has a roughly Gaussian form with peak magnitude g' = 24.0 and σ = 1.3 mag. In u^* and z', the S/N require-

[1] S/N for point sources are quoted in an "optimal" aperture of radius equal to 0.73 times the seeing FWHM.

ment is relaxed to S/N=5. Since the u^*-band is mostly needed for young stellar population studies, the depth is further relaxed by one magnitude, from the u^*=26.9 mag appropriate for an old, metal poor stellar population, to u^*=25.9 mag. Surface brightness limits are quoted at 2σ above the sky noise.

The u^* and g' images require dark skies. The r' images would require 40% shorter exposures in dark rather than grey time, however, grey time is requested to ease the scheduling constraints on the telescope (§T.5). The i' and z' exposure times are insensitive to moon illumination. To recover the gaps between the MegaCam CCDs, in each field/filter, exposures will be dithered using a standard "Large Dither Pattern" (LDP) with a minimum of 5 pointings.

To avoid saturation in the centres of brightest galaxies (which, at μ_z ~ 12 AB mag arcsec^{-2} will saturate in these "long" exposures) we will obtain a series of short exposures (Table 2) arranged in a five-point LDP. The magnitude at which S/N=5 is reached in the short exposures is brighter than the magnitude at which objects saturate in the long exposures, ensuring that all objects will be observed in the linear regime. Note that the short exposures are *not* sky-noise limited, so will not be combined with the long exposures.

The LDP strategy allows full sampling of a 1 deg^2 FOV. Adjacent fields will be overlapped by 3′ in RA and 4′ in Dec for photometric and astrometric calibration. Given that the central 4 deg^2 will be observed in 2008A as part of our approved pilot project, covering the remaining 100 deg^2 will require 113 pointings, plus an additional 4 pointings for our control fields. Table 3 summarizes the total time needed to complete the project. Note that the only overhead charged by CFHT is a 40s readout per exposure. The total time request will be split between France, Canada and Hawaii proportionally to their share of the telescope (40%, 40%, 15%). If Hawaii opts out of the LPs, the time will be split equally between Canada and France.

■ T.5 Scheduling.

The Virgo Cluster can be observed at an airmass ≤ 1.5 for more than 3.5 hr night^{-1} (up to a maximum of 6.6 hr night^{-1}) from mid-January to the third week of May (the window changes by about 10 days between the East and the West boundaries of the NGVS). Photometric conditions are requested in g' only, to minimize scattered light problems in the analysis of the large scale, low surface brightness features (§S.3.3). For the remaining filters, photometric conditions are not necessary since the photometric solution will be derived by matching source lists to the SDSS catalogues; experience with the CFHTLS shows that ~1000 SDSS stars deg^{-2} are available for this purpose.

Assuming an average 15 day MegaPrime run per lunation, implies that Virgo can be observed for a total of 473 hours each spring semester. Roughly speaking, if spread equally over the four spring semesters between 2009 and 2012, the NGVS would use 193 hours each spring semester, equivalent to ~40% of each MegaPrime 15-day run between mid-January and mid-May. This estimate is confirmed by a more detailed scheduling analysis, folding in the exact observability of the NGVS fields and the average number of MegaPrime validated hours during each semester.

■ T.6 Background/Foreground Contamination

Background and foreground objects are expected to become an increasingly dominant source of contamination at B magnitudes fainter than ~16.5 mag. In the VCC, cluster membership was established using known scaling relations between surface brightness

Table 2: Exposure Breakdown (for each MegaPrime field)

Filter	Long Exposures: Exposure Times	Long Exposures: Point Sources Detection Limit (AB mag) and S/N	Long Exposures: Extended Sources Detection Limit (AB mag arcsec^{-2}, 2σ)	Short Exposures: Exposure Times	Short Exposures: Point Sources Detection Limit (AB mag, S/N=5)	Seeing FWHM	% Moon Illumination
u^*	11×582s	25.9 (S/N=5)	27.3	5×50s	24.3	1.0″	10% (Dark)
g'	5×634s	25.7 (S/N=10)	27.7	5×12s	23.2	1.0″	10% (Dark)
r'	7×687s	25.2 (S/N=10)	27.2	5× 9s	22.2	1.0″	40% (Grey)
i'	5×411s	24.9 (S/N=10)	26.3	5× 8s	21.7	0.6″	>50% (Bright)
z'	8×550s	24.6 (S/N=5)	25.8	5×13s	21.2	1.0″	>50% (Bright)

Table 3: Exposure Summary

%Moon Illumination	Filters	Total Exposure Time per field	Total Overhead per field	Total Request per field	**Total Request (100 + 4 deg^2, 117 fields)**
0-20% (~10 days/month)	u^* + g'	2.744h	0.289h	3.033h	**355h**
20-50% (~10 days/month)	r'	1.349h	0.133h	1.482h	**173h**
>50% (~10 days/month)	i' + z'	1.822h	0.256h	2.078h	**243h**
Any	***All***	**5.915h**	**0.678h**	**6.593h**	**771h**

and total magnitude[9] (Fig. 3) — an approach that follow-up spectroscopy proved 95% effective. To safeguard against involuntarily selecting against "non-standard" galaxies, and to identify GSCs, we will additionally adopt the following three-fold approach:

1) About 80% of background and foreground objects can be identified with *colour-colour diagrams*; adding *photometric redshift* information further reduces the number of contaminants by a factor two. Fig. 4 shows colour-colour diagrams obtained for the CFHTLS D3 field, with magnitude cuts matching the completeness limit of the NGVS. There are ~65,000 objects deg^{-2}, of which ~11,000 have colours matching (within the photometric errors) those expected for Virgo galaxies, from irregular to early types. Photometric redshifts place all but ~5000 of these objects beyond Virgo; it follows that 1.4 objects arcmin^{-2} (and an order of magnitude less for unresolved sources) will be confused with Virgo members. For comparison, the average density of Virgo galaxies will be between ~0.04 and ~10 arcmin^{-2}, depending on the faint-end slope of the LF (§S.3.1), while the number of GSCs will be of order ~0.3 arcmin^{-2} at the survey boundaries, if these BSSs trace the ICM on cluster-wide scales[78].

2) A *statistical* estimate of background contamination will be derived using *four control fields* at the same Galactic latitude as Virgo, supplemented by the CFHTLS Wide and Deep fields (located at slightly lower galactic latitudes, $-62 \lesssim b \lesssim -42$ and $42 \lesssim b \lesssim 60$). These fields have similar, or longer, exposure times than the NGVS.

3) Multi-slit wide-field *spectroscopy* over selected areas of Virgo will be secured through our collaboration (§T.7). This will provide low-resolution spectroscopy for several tens of thousands objects, and a robust estimate of the relative number of background, foreground, and Virgo sources.

■ T.7 Coordinated Observations.

The NGVS is largely a self-contained project. However, multi-slit spectroscopy will be obtained by the collaboration to follow up potentially interesting sources, using VLT/VMOS (FOV = 220 arcmin^2), MMT/Hectospec (2800 arcmin^2), Magellan/IMACS (590 arcmin^2) and Subaru/MOIRCS (28 arcmin^2).

■ T.8 Synergies and Competition.

Virgo is arguably the most popular target in extragalactic astronomy (Fig. 1). The wealth of data available at wavelengths ranging from the radio to the X-ray will provide an obvious complement to the NGVS data. The properties of the X-ray gas have been extensively mapped by ROSAT and Chandra/XMM over the entire cluster and the core region, respectively. *GALEX* observed Virgo in the far and near UV as part of its *Medium Imaging* and *Nearby Galaxy Surveys* (and in numerous GI programmes). In the far-IR, Spitzer's *VIRGOFIR* survey will cover 30 deg^2 at 24 and 70 μm; at longer wavelengths, 60 deg^2 will be observed between 150 and 500 μm by a recently approved Hershel Legacy Survey (*HeViCS*). Two Arecibo surveys are ongoing, *ALFALFA* (covering the entire cluster) and *AGES* (25 deg^2 at higher sensitivity). In addition, hundreds of Virgo galaxies are the targets of large/legacy surveys. A sample of 100 early-type galaxies brighter than B_T=16.0 mag was observed in g' and z' with HST's Advanced Camera for Surveys (*ACSVCS*); for the same sample, images with Spitzer, Chandra, CFHT/WIRCam, and long slit spectra are available. Over 100 Virgo galaxies are part of *Herschel/SPIRE Reference Sample*. *Atlas3D*, a survey carried out with SAURON at WHT, will obtain IFU spectra of most early-type galaxies brighter than B_T=13 mag. *SHiVir*, a multi-telescope project, is collecting *H*-band images and longslit spectra for 299 Virgo galaxies, mostly spirals. CO and cool dust emission observations for 36 Virgo spirals will be obtained as part of JCMT/SCUBA-2 *Nearby Galaxy Legacy Survey*. Our NGVS team includes the PIs and CoIs of many of these complementary surveys.

Of the next generation of optical synoptic surveys, only LSST will outperform the NGVS, but not until the 2025 completion of its 10-year 20,000 deg^2 survey (with planned 5σ limiting AB magnitudes: u=26.1, g=27.4, r=27.5, i=26.8, z=26.1). Pan-STARRS in particular will *not* accomplish NGVS's main goals: at its completion in 2011, Pan-STARRS 3π survey will be ~2 magnitudes shallower than the NGVS, and with no u-band coverage[127]. Competition from PI programmes is also unlikely: MegaPrime is *the* most efficient instrument for wide-field surveys currently available. For instance, Suprime-Cam on Subaru, IMACS on Magellan, and VMOS on VLT have FOV smaller by factors 4, 6 and 16, respectively. The only serious competition in the foreseeable future is Subaru's Hyper-Suprime-Cam (HSC), with FOV between 1.8 and 3.1 deg^2, and first light expected in 2010/2011. HSC will be 10× more efficient than MegaPrime. The question is therefore whether the NGVS could be done better, and not simply faster, with an 8m-class telescope. We believe the answer is no: the NGVS is ideally matched to the capabilities of MegaPrime — not only is it the kind of project that CFHT does best, but it can do it *first*. The NGVS is a survey for which CFHT should be remembered.

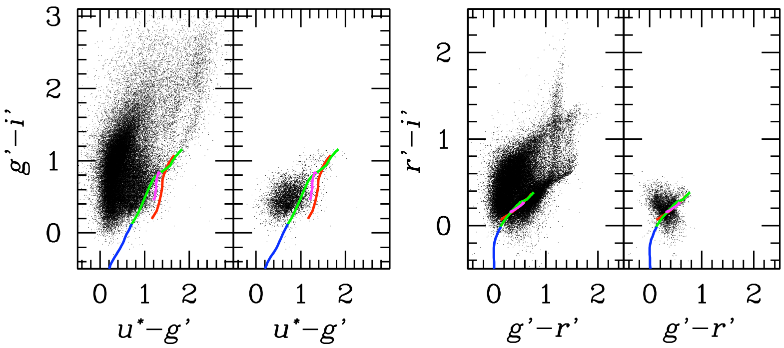

Figure 4. Background/foreground contamination expected in the NGVS, estimated using CFHTLS data matching the photometric limit of the NGVS. For each colour combination, the left panel shows all objects detected within this limit, while the right panel shows a cleaned sample obtained by rejecting sources which, based on photometric redshifts, are beyond Virgo at the 3σ confidence level. The solid lines represent evolutionary tracks for elliptical galaxies (red), metal-poor GSCs (magenta), S0 galaxies (green) and Irregular galaxies (blue). The u^* band is essential to: (1) measure accurate photometric redshifts and reduce the overall level of contamination; and (2) distinguish different stellar populations as a result of its sensitivity to young stars. In particular, the number of background/foreground contaminants is reduced by a factor 3 when u^* is used in combination with the redder passbands.

■ Data Management Plan

■ D.1 Data Reduction and Analysis.

The NGVS will benefit from the well-oiled machinery developed to support the CFHTLS. Validation and pre-processing of MegaPrime images will be carried out by the *Elixir* pipeline[71,125], which performs bad pixel masking, bias and overscan correction, flat-fielding, fringe correction for the *i*' and *z*' images, and photometric calibration. *Elixir* pre-processed images are routinely generated within four days of the end of each MegaPrime run, and are immediately made available for download through the Canadian Astronomy Data Centre (CADC[128], physically located at NRC/HIA, Victoria). Global astrometric solutions, image stacking and source catalogues will be generated by *MegaPipe* [129](a project funded and maintained by CADC with the support of the Canadian Space Agency) and, independently, by *Terapix*[126] (a data reduction centre located at the Institut d'Astrophysique in Paris, France). Both *MegaPipe* and *Terapix* have been responsible for the processing of all CFHTLS data.

Members of our team have developed extensive software suitable for the analysis of the NGVS data: GalFit[94], GIM2D[106] , KingPhot[59], a series of codes used in the ACS "Virgo Cluster Survey"[21] for the photometric and structural analysis of Virgo galaxies, and multi-scale filters using Fourier convolution techniques optimized for the detection of LSB galaxies[102]; plus several algorithms developed for SBF[81] and weak lensing analysis[55], and measurement of photometric redshifts[49]. L. Ferrarese is CoIs on a $2 million dollar proposal submitted to Canada's Advanced Internet Development Organization (CANARIE) that would fund the network, hardware, and software development for one (possibly two) of three specific Large Programmes, including the NGVS. The grant will allow the hire of up to 11 FTE (postdocs and software specialists). The proposal is one of 14 (out of 51 submitted) approved by CANARIE for further study; it is expected that ~10 proposals will receive funding. A decision will be announced in May, and hires will be made with a Sept. 2008 starting date. The software interface to be developed will include automated pipelines for source detection and structural analysis of extended objects, identification of background clusters and strong lensing features, cross correlation with existing multi-wavelength Virgo surveys, as well as the ability to carry out extensive simulations to test selection effects. Optimization of this pipeline, which will be accessible to team members through the CADC, will commence using data from our pilot project, in hand by May 2008.

■ D.2 Data Distribution.

All data and data products will be stored at and distributed by the CADC. Real-time updates on the data acquisition, as well as regular status reports will be posted on a dedicated web-page maintained by the CADC at HIA. The sharing of proprietary data products and software between the team members will be managed through a protected area within the main webpage. A TWiki-based section within this area will allow team members to post progress reports on specific projects involving the NGVS data and follow-up observations.

■ D.3 Team expertise.

Members of our team are deeply involved in, and in several cases *leading*, a number of the surveys described in §T.8 (i.e., *HeViCS, JCMT/NGLS, ALFALFA, AGES, GALEX Virgo Survey, ACSVCS* and complementary data, *Atlas3D, ICLVS, SHiVir*). Within the collaboration we therefore have the access, resources and expertise to fully capitalize on this uniquely rich dataset. A list of expertise for each team member can be found on the NGVS web-site:

http://astrowww.phys.uvic.ca/~lff/NGVS.html

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