GEMINI OBSERVATORY

observing time request summary

Semester: 2014B **Observing Mode:** Large Program **Gemini Reference:**

Instruments: GMOS South

Time Awarded: NaN **Thesis:** No

Band 3 Acceptable: No

Title: **The GOGREEN Survey of dense galaxy environments at 1<z<1.5**

Principal Investigator: **Michael Balogh**

PI institution: University of Waterloo, Department of Physics and Astronomy
Waterloo Ontario N2L 3G1, Canada

PI status: PhD

PI phone/e-mail: 519 888 4567 x37518 / mbalogh@uwaterloo.ca

Co-Investigators:
Bob Abraham: University of Toronto, abraham@astro.utoronto.ca
M. Victoria Alonso: Universidad Nacional de Cordoba (Observatorio), m.v.alonso@gmail.com
Andrea Biviano: INAF/Trieste, biviano@oats.inaf.it
Richard Bower: Durham University, r.g.bower@durham.ac.uk
Charlie Conroy: UC Santa Cruz, conroy@ucsc.edu
Michael Cooper: UC Irvine, m.cooper@uci.edu
Warrick Couch: Australian Astronomical Observatory, warrick.couch@aao.gov.au
Andrew de Groot: UC Riverside, adegr001@ucr.edu
Gabriella De Lucia: INAF/Trieste, delucia@oats.inaf.it
Ricardo Demarco: Universidad de Concepcion, rdemarco@astro-udec.cl
Erica Ellingson: University of Colorado at Boulder (CASA), Erica.Ellingson@colorado.edu
Alexis Finoguenov: Helsinki, alexis.finoguenov@helsinki.fi
David Gilbank: SAAO, gilbank@saao.ac.za
Henk Hoekstra: Leiden University, hoekstra@strw.leidenuniv.nl
Dennis Just: University of Toronto, just@astro.utoronto.ca
Mark David Lacy: NRAO Headquarters, markdavidlacy@gmail.com
Diego Garcia Lambas: Universidad Nacional de Cordoba (Observatorio), dgl@mail.oac.uncor.edu
Chris Lidman: Australian Astronomical Observatory, clidman@aao.gov.au
Ian McCarthy: Liverpool John Moores University, i.g.mccarthy@ljmu.ac.uk
Sean McGee: Leiden University, mcgee@strw.leidenuniv.nl
Hernan Muriel: Universidad Nacional de Cordoba (Observatorio), hernan@oac.uncor.edu
Adam Muzzin: Leiden University, muzzin@strw.leidenuniv.nl

GEMINI OBSERVATORY

observing time request summary

Julie Nantais: Universidad de Concepcion, jnantais@astro-udec.cl
Allison Noble: University of Toronto, noble@astro.utoronto.ca
Matt Owers: Australian Astronomical Observatory, mowers@aao.gov.au
Laura Parker: McMaster University, lparker@physics.mcmaster.ca
Bianca Poggianti: INAF/Padova, bianca.poggianti@oapd.inaf.it
Alessandro Rettura: Jet Propulsion Laboratory, arettura@astro.caltech.edu
Greg Rudnick: University of Kansas, grudnick@ku.edu
Ian Smail: Durham University, ian.smail@durham.ac.uk
Jason Surace: Caltech IPAC, jason@ipac.caltech.edu
Jeremy Tinker: NYU, jl12@nyu.edu
Carlos Valotto: Universidad Nacional de Cordoba (Observatorio), val@mail.oac.uncor.edu
Remco van der Burg: Leiden University, rfjvanderburg@gmail.com
Tracy Webb: McGill University, webb@physics.mcgill.ca
Andrew Wetzel: Caltech Astronomy and Carnegie Observatories, awetzel@caltech.edu
Jon Willis: University of Victoria, jwillis@uvic.ca
Gillian Wilson: UC Riverside, gillian.wilson@ucr.edu
Howard Yee: University of Toronto, hyee@astro.utoronto.ca
Dennis Zaritsky: University of Arizona (Astronomy), dennis.zaritsky@gmail.com

---

Partner Submission Details *(multiple entries for joint proposals)*

	PI Request			NTAC Recommendation			
Partner	**Lead**	**Time**	**Min**	**Reference**	**Time**	**Min**	**Rank**
	First Semester	*39.8 hr*	*39.8 hr*		*0.0 hr*	*0.0 hr*	
	Total Time	*438.4 hr*	*438.4 hr*				

Abstract

Gemini-GMOS is the best instrument in the world for studying distant galaxy clusters, and the upgrade to Hamamatsu detectors allows us to make a monumental advance in our understanding of how environment influences galaxy evolution. The GOGREEN survey will obtain multi-object spectroscopy of 21 galaxy clusters in the redshift range $1<z<1.5$, selected to be the progenitors of today's massive clusters. The sample of >1000 spectroscopically confirmed cluster members reaches unprecedented stellar masses at this redshift, providing the first look at environmental effects on galaxy evolution at a time when galaxies are growing in a fundamentally different way from today. Spectroscopy allows us to measure the dynamics of different galaxy populations, their relative stellar population ages, and to obtain a robust measurement of the abundance of low-mass, quiescent galaxies. Our international team of experts includes theorists with a wealth of experience in interpreting cluster data with simulations and analytic models. By combining GOGREEN with our own data on the lower-redshift descendants, we will measure the evolution of satellite galaxy dynamics and stellar populations over the last 9.3 Gyr of cosmic time. This will provide unique leverage to theoretical models, importantly testing them at an epoch where there are currently almost no constraints.

GEMINI OBSERVATORY

observing time request summary

TAC Category / Keywords

Extragalactic / Survey, Stellar populations, Redshifts, Mass function, Groups of galaxies, Galaxy clusters, Evolution, Emission lines, Elliptical galaxies, Dark matter, Absorption lines

Potential Problems

The submitted proposal has 3 observations that have poor visibility this semester, 15 observations with a low probability of suitable guide stars, and 2 observations with duplicate datasets in the GSA.

Scheduling Constraints

Deep imaging observations in z' must be obtained well in advance of the spectroscopy, for mask design. This is critical for SPT-CL J0546 and SpARCS CDFS-41 as we plan to make spectroscopic observations this semester. We request these be taken in queue mode as early as possible.

LPTAC information

Decision	Ranking	Recommended Time	Staff Support Email
		( )	

Comments

Observation Details (Band 1/2)

Observation	RA	Dec	Brightness	Total Time *(including overheads)*
SXDF76XGG	02:18:57.912	-05:19:23.880		1.7 hr
Potential problems: Many PAs do not have suitable guide stars (33%). Review if a specific PA is required. **Conditions:** CC 50%/Clear, IQ 20%/Best, SB 50%/Dark, WV Any **Resources:** GMOS-S Imaging z (925 nm)				
SXDF49XGG	02:18:08.328	-05:04:17.040		1.7 hr
Potential problems: Many PAs do not have suitable guide stars (6%). Review if a specific PA is required. **Conditions:** CC 50%/Clear, IQ 20%/Best, SB 50%/Dark, WV Any **Resources:** GMOS-S Imaging z (925 nm)				
GCLASS J0035	00:35:49.704	-43:12:24.480		1.7 hr
Potential problems: Many PAs do not have suitable guide stars (39%). Review if a specific PA is required. ; 50 duplicate datasets in the GSA **Conditions:** CC 50%/Clear, IQ 20%/Best, SB 80%/Grey, WV Any **Resources:** GMOS-S Imaging z (925 nm)				
GCLASS J0215	02:15:24.000	-03:43:32.160		1.7 hr
Potential problems: Some PAs do not have suitable guide stars (61%) ; 10 duplicate datasets in the GSA **Conditions:** CC 70%/Cirrus, IQ 70%/Good, SB 80%/Grey, WV Any **Resources:** GMOS-S Imaging z (925 nm)				
COSMOS 221	10:02:16.848	02:29:54.960		6.5 hr
Potential problems: Some PAs do not have suitable guide stars (69%) ; Visibility is limited **Conditions:** CC 70%/Cirrus, IQ 70%/Good, SB 80%/Grey, WV Any **Resources:** GMOS-S MOS N+S 1.0 arcsec slit R150 RG610 (> 615 nm)				
SPT-CL J0546-5345	05:46:00.000	-53:53:60.000		7.8 hr
Potential problems: Many PAs do not have suitable guide stars (39%). Review if a specific PA is required. **Conditions:** CC 70%/Cirrus, IQ 70%/Good, SB 80%/Grey, WV Any **Resources:** GMOS-S MOS N+S 1.0 arcsec slit R150 RG610 (> 615 nm)				
SPT-CL J0205-5829	02:04:60.000	-58:28:48.000		1.7 hr
Potential problems: Many PAs do not have suitable guide stars (47%). Review if a specific PA is required. **Conditions:** CC 70%/Cirrus, IQ 70%/Good, SB 80%/Grey, WV Any **Resources:** GMOS-S Imaging z (925 nm)				
SPT-CL J0546-5345	05:46:00.000	-53:53:60.000		1.7 hr
Potential problems: Many PAs do not have suitable guide stars (39%). Review if a specific PA is required. **Conditions:** CC 70%/Cirrus, IQ 70%/Good, SB 80%/Grey, WV Any **Resources:** GMOS-S Imaging z (925 nm)				

SXDF64XGG	02:16:57.120	-05:10:17.040		1.7 hr

Potential problems: Some PAs do not have suitable guide stars (53%)
Conditions: CC 70%/Cirrus, IQ 70%/Good, SB 80%/Grey, WV Any
Resources: GMOS-S Imaging z (925 nm)

SpARCS CDFS-41	03:35:03.576	-29:28:55.920		1.7 hr

Potential problems: Many PAs do not have suitable guide stars (14%). Review if a specific PA is required.
Conditions: CC 70%/Cirrus, IQ 70%/Good, SB 80%/Grey, WV Any
Resources: GMOS-S Imaging z (925 nm)

SpARCS XMM-67	02:19:43.584	-05:31:29.640		1.7 hr

Potential problems: Some PAs do not have suitable guide stars (78%)
Conditions: CC 70%/Cirrus, IQ 70%/Good, SB 80%/Grey, WV Any
Resources: GMOS-S Imaging z (925 nm)

SpARCS CDFS-41	03:35:03.576	-29:28:55.920		7.8 hr

Potential problems: Many PAs do not have suitable guide stars (14%). Review if a specific PA is required.
Conditions: CC 70%/Cirrus, IQ 70%/Good, SB 80%/Grey, WV Any
Resources: GMOS-S MOS N+S 1.0 arcsec slit R150 RG610 (> 615 nm)

SXDF60XGG	02:16:45.456	-05:09:48.600		1.7 hr

Potential problems: Some PAs do not have suitable guide stars (53%)
Conditions: CC 70%/Cirrus, IQ 70%/Good, SB 80%/Grey, WV Any
Resources: GMOS-S Imaging z (925 nm)

COSMOS-221	10:02:16.848	02:29:54.960		0.4 hr

Potential problems: Some PAs do not have suitable guide stars (69%) ; Visibility is limited
Conditions: CC 70%/Cirrus, IQ 70%/Good, SB 80%/Grey, WV Any
Resources: GMOS-S Imaging z (925 nm)

COSMOS 125	10:02:30.528	02:09:33.120		0.4 hr

Potential problems: Many PAs do not have suitable guide stars (44%). Review if a specific PA is required. ; Visibility is limited
Conditions: CC 70%/Cirrus, IQ 70%/Good, SB 80%/Grey, WV Any
Resources: GMOS-S Imaging z (925 nm)

Scientific Justification

The GOGREEN Survey: caring for the environment

Background: Galaxy clusters are extraordinarily valuable as laboratories for a wide range of tests and experiments. They play a central role in studies of cosmology, galaxy and structure formation, as well as plasma physics and supermassive black hole growth, and for the determination of the nature of dark matter. Their enormous gravitational potentials allow them to act as cosmic "calorimeters", maintaining an observable record of all the energy inputs and outputs associated with galaxy formation over the history of the Universe. They host the most massive galaxies, which are among the first luminous objects to form. Clusters are also the ideal places to study rare and extraordinary perturbations to galaxy evolution, such as hydrodynamic stripping of gas, tidal stripping of matter, and high-speed gravitational encounters. Much of what we have learned about galaxy evolution is thanks to years of research on these systems.

In the past decade, the extragalactic community has invested heavily in *Legacy* galaxy redshift surveys over the redshift range $0 < z < 1.2$. Surveys like zCOSMOS, VVDS, VIPERS, DEEP2 and others comprise > 1000 nights of 8m telescope time, and have enabled transformative leaps in our understanding of galaxy evolution. Notably, Gemini has not been a major participant in this 8m-class science, despite having an optical MOS. This is simply because the smaller field of view makes GMOS uncompetitive with instruments like DEIMOS and VIMOS for large-area surveys. However, GMOS has several unique capabilities that give it a performance advantage over these instruments. The nod-and-shuffle (n&s) mode allows excellent sky subtraction at red wavelengths, resulting in much greater efficiency for faint galaxies (as exploited by GDDS, Abraham et al. 2004). Moreover, the n&s microslits are three times smaller than normal slits, allowing them to be placed with a very high surface density. Now, the upcoming Hamamatsu upgrade will make GMOS the most red-sensitive optical spectrograph on an 8m telescope. These advantages make GMOS the best instrument in the world for multiobject spectroscopy of distant clusters and groups, where galaxy densities are high and galaxies are faint and red.

At $z > 1$, when the gas accretion rates, relative gas mass and star formation rates of galaxies were so much higher than they are today, the interactions between galaxies and their environments are also expected to be very different. *Yet the properties of typical galaxies in $z > 1$ clusters are almost completely unknown.* Thus we propose the ultimate distant-cluster legacy survey with *Gemini Observations of Galaxies in Rich Early ENvironments (GOGREEN)*. The targets are 21 galaxy clusters at $1 < z < 1.5$, chosen to span a range in halo mass: Coma-progenitors, Virgo-progenitors, and massive groups, as shown in Figure 1. GOGREEN builds upon the work we have done with Gemini in constructing the GCLASS cluster (Muzzin et al. 2012) and GEEC2 group (Balogh et al. 2011) samples, and the lower redshift ($0.8 < z < 1$) systems from those surveys will be included as part of the GOGREEN data release. With homogeneous, deep spectroscopy of over ~ 1000 cluster members, GOGREEN will be the definitive redshift survey of galaxies in massive haloes ($M > 10^{13} M_{\odot}$) at this redshift for many years: no spectrograph on the horizon is able to compete.

In addition to its Legacy value, the survey design is optimized to address three main topics:

Environmental quenching and growth of the stellar mass function: Despite a solid theoretical foundation for the gravitational growth of dark matter structure, no galaxy formation model of any type has been able to successfully explain a) the rate of decline in global SFR; b) the mass dependence of this decline; or c) the star formation histories of satellite galaxies (Bower et al. 2012; Wang et al. 2012; Weinmann et al. 2012; De Lucia et al. 2012). These problems may be related, as they are all sensitive to assumptions about how gas accretion, ejection and heating processes depend on epoch, environment and halo mass (McGee et al. 2014). The conventional

Sample	ID	RA	Dec	z	Nm x t(h)
		Groups			
SXDF	64XGG	34.3238	-5.1714	1.0300	3x5
SXDF	49XGG	34.5347	-5.0714	1.0590	3x5
COSMOS	221	150.5702	2.4986	1.1460	3x5
COSMOS	63	150.3533	1.9334	1.2340	3x5
COSMOS	28	149.4576	1.6724	1.2580	3x5
SXDF	76XGG	34.7413	-5.3233	1.4000	3x5
SXDF	60XGG	34.1894	-5.1635	1.4100	3x5
COSMOS	125	150.6272	2.1592	1.4500	3x5
CDFS	2	53.0017	-27.5790	1.4700	3x5
		Virgo Progenitors			
GCLASS	J0215	33.8500	-3.7256	1.0040	3x5
GCLASS	J1051	162.7968	58.3009	1.0350	3x5
GCLASS	J1634	248.6475	40.3643	1.1770	3x5
GCLASS	J1638	249.7152	40.6453	1.1960	3x5
SpARCS	XMM-67	34.9316	-5.5249	1.3000	5x3
GCLASS	J0035	8.9571	-43.2068	1.3350	5x3
SpARCS	CDFS-41	53.7649	-29.4822	1.3680	5x3
SpARCS	L-77	158.7060	58.3092	1.4000	5x3
SpARCS	L-100	158.3565	57.8900	1.4550	5x3
		Coma Progenitors			
SPT-CL	J0546-5345	86.5000	-53.9000	1.0670	5x3
SPT-CL	J2106-58	316.5000	-58.7300	1.1320	5x3
SPT-CL	J0205-5829	31.2500	-58.4800	1.3200	5x3

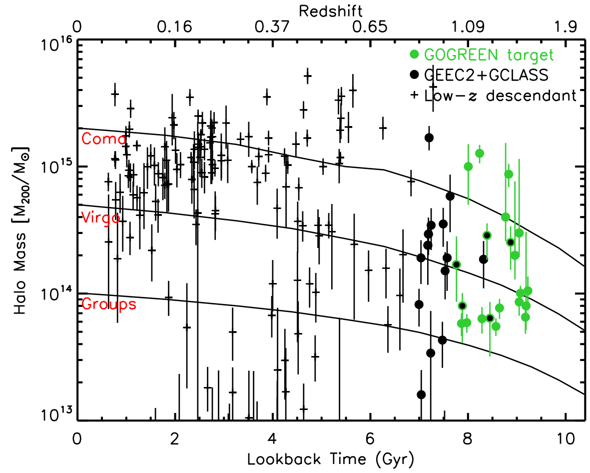


Figure 1: The table lists our targets; the final column shows the total spectroscopic exposure time that will be obtained as part of GOGREEN ($N_{mask} \times t_{\rm exp}$). The figure shows how GOGREEN relates to our existing GEEC2 and GCLASS samples, as well as lower redshift surveys (EDisCS, MeNEACS, CCCP, CNOC, GEEC1 and CLASH) that we will use as direct comparisons. Lines are theoretical growth curves from the Millennium simulation.

picture of the interaction between galaxies and their surroundings is that galaxies enter dense environments with a reservoir of gas (either in the stellar disk, or the halo), and that star formation declines as this reservoir is removed (e.g. Balogh et al. 2000; Bower et al. 2006). This view is out of date. Cosmological simulations show that galaxies grow as a result of continuous infall from surrounding filaments, a scenario that is supported by indirect observational arguments (e.g. Davé et al. 2012, Lilly et al. 2013). While a reservoir may play a role at low redshift, at higher redshift the supply of fresh gas fully dominates over the consumption of the reservoir. This change leads to a prediction that dense environments shut down star formation even more rapidly at $z > 1$ than at low redshift, in stark contrast with the old model (McGee et al. 2014). This sensitivity allows us to use trends with environment to understand the nature of gas accretion, which is fundamental to the evolution of *all* galaxies.

Simple but powerful indicators of SFR suppression (or “quenching”) are the evolution of the quiescent galaxy stellar mass function, and the stellar–mass dependence of the quiescent fraction. In the general field the quiescent galaxy mass function evolves rapidly, as star formation is shut down first in the most massive galaxies, and later in dwarfs (e.g. Muzzin et al. 2013). In massive clusters this is clearly seen as the growth of the “red sequence” (e.g. Rudnick et al. 2012). At $z < 1$, most models predict many more low-mass, quiescent galaxies than are observed (Figure 2), a consequence of the well-established overquenching problem (Weinmann et al. 2011). It is unknown if this problem persists at higher redshift, where the gas content, accretion rates and star formation rates of galaxies are so much higher, and even galaxies in cluster cores have only been satellites for a few Gyr. GOGREEN will be the first spectroscopic study of satellite galaxies at $1 < z < 1.5$ with the depth required to reach the low stellar-mass galaxies that are predicted to be most sensitive to environmental quenching. From these measurements alone it is possible to put strong constraints on the associated timescales (e.g. Tinker & Wetzel 2010), the evolution of which is a powerful indicator of how gas-supply and removal mechanisms change with time (McGee et al. 2014). Moreover, the higher average star formation rate of field galaxies, and the increased rate at which they are accreted by the cluster, translates directly into a much higher fraction of galaxies observed in the “transition phase” between actively star–forming and quiescent (Mok et

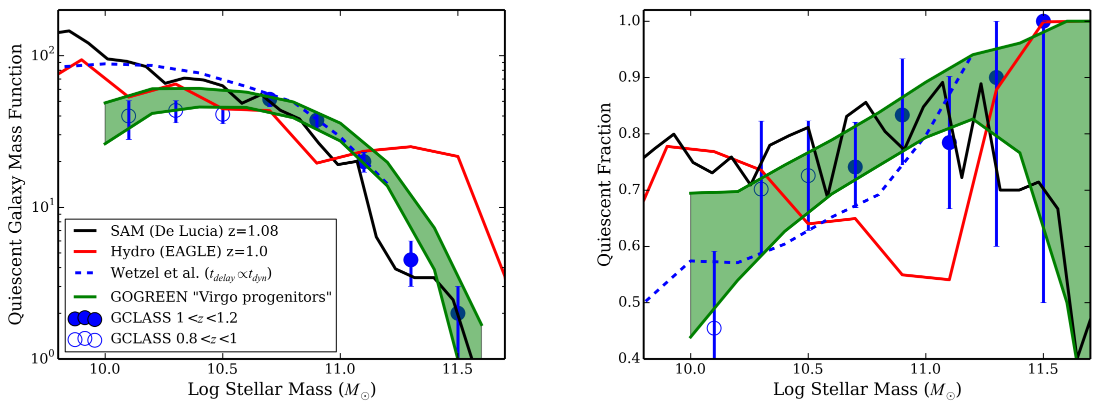


Figure 2: Left: Filled points represent the spectroscopic stellar mass function of quiescent galaxies at $0.8 < z < 1.2$ from GCLASS, compared with three of our model predictions. The observed mass function is flat, while *all three independent models predict a steep slope at* $z > 1$. The predicted precision of GOGREEN-Virgo at $1 < z < 1.5$ is shown as the shaded region. GOGREEN is designed to achieve comparable precision in the sample of Groups and Coma-progenitors, not shown here. Right: The fraction of quiescent galaxies from GCLASS is compared with the same models. GOGREEN will have the precision to distinguish between the predictions of these models, which make fundamentally different assumptions about how galaxies get their gas.

al. 2014). Exceptional sensitivity to the galaxy transformation timescale can be obtained from fairly straightforward modeling of the radial gradients and pseudo-phase space distribution of such subpopulations, compared with the quiescent and star–forming galaxies (e.g. Balogh et al. 2000, Ellingson et al. 2001, Noble et al. 2013; Muzzin et al. 2014; see Figure 3).

The hierarchical assembly of baryons: It is a fundamental prediction of ΛCDM theory that massive clusters are built from haloes of lower mass: groups and isolated galaxies. Since it is difficult to preferentially remove stars from dark matter dominated systems, when these systems merge the fraction of total mass in stars can only increase (via star formation) or remain constant. Therefore, measurement of the stellar fraction, gas fraction, and star formation rate in haloes of a given mass provide one of the closest possible links between galaxies and this basic prediction of the underlying theoretical framework (Balogh et al. 2008). Precision measurements of this type are essential for calibrating and constraining models, and are an essential complement to abundance-matching or HOD model approaches (e.g. Behroozi et al. 2013). *With GOGREEN we will directly measure the central and total stellar mass of haloes out to* $z = 1.5$ *for the first time.* Importantly, the intracluster light is expected to be negligible at $z = 1.5$, as there has been little time for the required tidal stripping to occur. Thus, our census of stars will be close to complete, and a good comparison for theory.

The spatial and dynamical distribution of cluster galaxies is sensitive not only to the field accretion rate, but also to the dynamical friction time and galaxy merger and disruption timescales. These rates are not well understood theoretically, despite being primarily gravitational processes, and observations of these distributions provide valuable constraints, as we have shown with GCLASS (e.g. van der Burg et al. 2014).

Finally, GOGREEN is designed to have high spectroscopic completeness (> 50 per cent) in all systems, which will allow a measurement of dynamical substructure within the clusters, and in the infall regions. The cluster sample is sufficiently large that we will be able to investigate whether

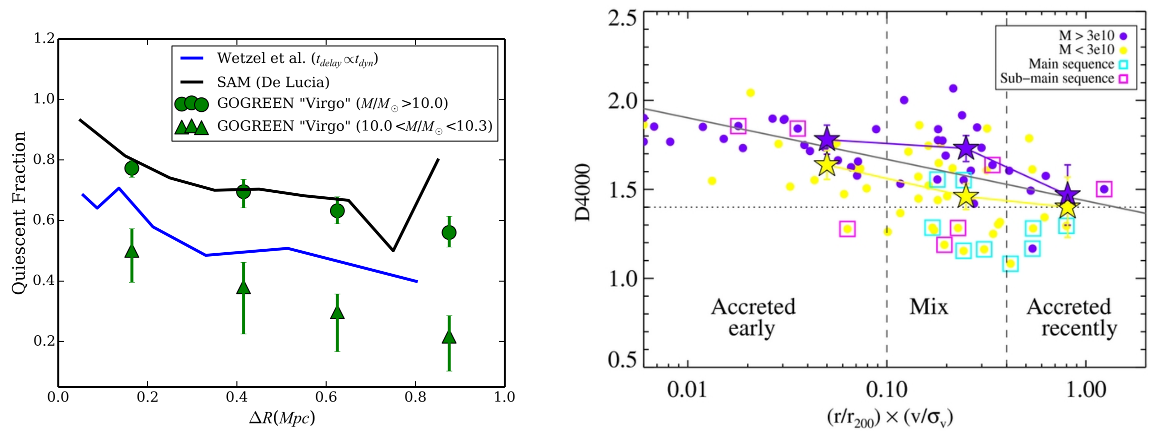


Figure 3: *Left:* The quiescent fraction at $z = 1$ is shown as a function of clustercentric distance, for the De Lucia SAM and the Wetzel models from Figure 2, with the precision of the GOGREEN "Virgo progenitor" cluster survey indicated by the green points with error bars (in two stellar mass bins). We will have comparable precision for the "Group" and "Coma progenitor" cluster samples. *Right:* From Noble et al. (2013). By combining projected radius with dynamics (velocity offset), we have shown that it is possible to better distinguish galaxies by accretion time, and make an informative comparison with models (see also Muzzin et al. 2014). Here we see a gradient in age-sensitive D4000 as a function the "phase-space" quantity on the x-axis, for a single cluster at $z = 0.872$. GOGREEN will allow us to do this with a sample > 10 times larger, at $1 < z < 1.5$.

the galaxy populations *at fixed halo mass* depend on the presence of substructure. Moreover, by producing a stacked sample of galaxies within the substructures themselves we will measure how their quiescent population varies with cluster-centric radius. By comparing this with the trends measured for the bulk of the cluster population, we will constrain the timescale over which satellite galaxies retain knowledge of their host halo after being accreted by a more massive structure.

Cluster Dynamics and Masses: At low redshift, the total mass content and distribution of galaxy clusters can be estimated by gravitational lensing, the assumption of hydrostatic equilibrium of the intracluster plasma, or the distribution and kinematics of cluster galaxies. The latter method always provides critical independent information from the other two, and is especially important for clusters at high redshifts, which are notoriously difficult to detect by their X-ray emission or weak lensing signal. At $z > 1.0$ our knowledge of the mass profiles of galaxy clusters is therefore limited to only a few individual clusters. GOGREEN represents a breakthrough in this field, by providing measurements of the dynamics of individual haloes at $1 < z < 1.5$ and, by stacking clusters, an unprecedented characterization of haloes from $\sim 5 \times 10^{13} M_\odot$ to $\sim 10^{15} M_\odot$.

Dynamical analyses of nearby clusters have shown their $M(r)$ to be well characterized by either a NFW (Navarro et al. 1997) or an Einasto et al. (1974) profile, passive galaxy orbits to be isotropic and star–forming galaxy orbits to be radially elongated (e.g. Biviano and Girardi 2003; Biviano and Katgert 2004). The NFW and Einasto model appear to also fit well the $M(r)$ of $z \sim 0.6$ clusters, but the orbits of passive galaxies evolve with z, and at $z \sim 0.6$ are more similar to those of star–forming galaxies (Biviano and Poggianti 2009; Biviano et al. 2013). With GOGREEN we will trace this evolution to unprecedented redshifts. We will be able to measure whether the NFW and Einasto models remain valid representations of the cluster $M(r)$, which is particularly interesting as the onset of dynamical equilibrium in galaxy clusters is still a poorly understood process (e.g., Dehnen & McLaughlin 2005). Combined with the velocity anisotropy profile $\beta(r)$ we can measure the more fundamental pseudo-phase space profile (Lapi & Cavaliere 2009; Dehnen & McLaughlin 2005). Evolution in this profile can distinguish between cluster assembly via fast, violent relaxation processes and smooth accretion of matter from the field (Hansen 2009).

Legacy Science: The main *Legacy* of GOGREEN will be to provide the high-density complement to the wide-field redshift surveys carried out by ESO and Keck, extending our knowledge of galaxy evolution to the full range of environments. In addition, the timing of our survey is well-matched to that of many forthcoming wide-field imaging cluster surveys. eRosita, Euclid and LSST will find large samples of high-redshift clusters, but require the type of data GOGREEN will provide to calibrate their observable quantitites in way that is necessary for cosmological applications.

The low-luminosity AGN content of clusters is poorly constrained at any redshift, and completely unknown at $1.0 < z < 1.5$. The fraction of these galaxies in optically selected clusters at high redshift is important for understanding the X-ray selection function used in cluster cosmology surveys like eRosita and XMM-XXL. These surveys devote considerable effort to determining the AGN contamination rate to their flux estimates, but this measurement is biased because it is measured from X–ray selected samples. In addition, the importance of large samples and well-understood selection effects have proven to be essential for understanding AGN triggering mechanisms. Various studies (e.g. Tanaka et al. 2012, Bongiorno et al 2012) have shown that AGN activity is linked to star formation activity; thus, measuring their environmental dependence provides an independent look at how galaxies respond to a change in their gas supply. With spectroscopy it is possible to also measure the velocity and phase-space distribution of the AGN population, to determine if there is a dynamical link with post-starburst galaxies (e.g. Muzzin et al. 2014).

A byproduct of our survey will be a deep field survey of > 600 galaxies at $1.0 < z < 1.5$, with homogeneous and well-understood selection criteria. At present, none of the existing wide-field spectroscopic surveys have the red sensitivity to match GOGREEN depth at $1.3 < z < 1.5$. Claims about evolution in the stellar mass function, star formation history etc. are based on photometric redshifts, which are notoriously unreliable in regions of parameter space where spectroscopic calibration is unavailable. The GOGREEN field survey will be twice the size of GDDS, and 0.5 mag deeper, allowing an unparalleled spectroscopic measurement of the galaxy mass function, separated by galaxy type. It will provide a crucial calibration sample for photometric redshifts out to $z = 1.5$, needed by surveys like LSST and PanStarrs. Finally we anticipate a serendipitous sample of > 10 massive galaxy groups, given the large total survey volume of $9 \times 10^5 \mathrm{Mpc}^3$, the spectroscopic sampling rate, and the halo mass function (Tinker et al. 2008). These can in fact be added to our primary sample (as we did with GEEC2).

References

Abraham et al. 2004 AJ 127, 2455
Balogh et al. 2011 MNRAS 412, 947
Biviano, A., Katgert, P. 2004, A&A, 424, 779
Biviano, A. et al. 2013, A&A, 558, A1
Bower, R et al. 2012, MNRAS, 422, 2816
Dave et al. 2012, MNRAS 421, 98
De Lucia et al. 2012, MNRAS 423, 1277
Ellingson et al. 2001, ApJ 547, 609
Hansen, S.H. 2009, ApJ, 694, 1250
Lilly et al. 2013, ApJ 772, 119
Muzzin et al. 2009 ApJ 698, 1934
Muzzin et al. 2013, ApJ 777, 18
Mok et al. 2013 MNRAS 431, 1090
Noble et al. 2013, ApJ 768, 118
Tanaka et al. 2012, PASJ 64, 22
Wang, L et al. 2012, MNRAS 421, 3450
Wetzel et al. 2013, MNRAS 432, 336
Yan & Blanton 2012, ApJ 747, 61
Balogh et al. 2000, MNRAS 540, 113
Behroozi et al. 2013, ApJ 763, 18
Biviano, A. et al. 2006, A&A, 456, 23
Bongiorno et al. 2012, MNRAS 427, 3103
Brodwin et al. 2010 ApJ 721, 90
Diaferio, A., Geller, M. 1997, ApJ, 481, 633
Demarco et al. 2010, ApJ 725, 1252
Foley et al. 2011 ApJ 731, 86
Hayashi et al. 2013 MNRAS 430, 1042
Mamon, G., Biviano, A., Boué, G. 2013, MNRAS, 429, 3079
Muzzin et al. 2014 ApJ, submitted
Muzzin et al. 2013, ApJ 767, 39
Mok et al. 2014, MNRAS 438, 3070
Rudnick et al. 2012, ApJ 755, 14
Tinker et al. 2008 ApJ 688, 709
Weinmann et al. 2011, MNRAS 416, 1197
Wilson et al. 2009 ApJ 698, 1943
Yan et al. 2009 MNRAS 398, 735
Balogh et al. 2008, MNRAS 385, 1003
Biviano, A., Girardi, M. 2003, ApJ, 585, 205
Biviano, A., Poggianti, B.M. 2009, A&A, 501, 419
Bower et al. 2006, MNRAS 370, 645
Conroy et al. 2014 ApJ 780, 33
Dehnen, W., McLaughlin, D.E. 2005, MNRAS, 363, 1057
Einasto et al. 1974, Nature 250, 309
Gilbank et al. 2011 MNRAS 412, 2111
Lidman et al. 2012 MNRAS 427, 550
McGee et al. 2009 MNRAS 400, 937
Muzzin et al. 2012 ApJ 746, 188
McGee et al. 2014, MNRAS, submitted
Navarro et al. 1997 ApJ 490, 493
Stalder et al. 2013 ApJ 763, 93
Tinker & Wetzel 2010 ApJ 719, 88
Weinmann, S. et al. 2012, MNRAS 426, 2797
van der Burg et al. 2014, A&A, 561, 79

Experimental Design

Cluster selection and sample size: Our primary goals are to measure the populations and dynamics of cluster members, as a function of cluster-centric radius and stellar mass, in three bins of halo mass: massive groups ($M < 10^{14}M_{\odot}$), Virgo-progenitors ($10^{14} < M/M_{\odot} < 5 \times 10^{14}$), and massive, Coma-progenitors ($M > 5 \times 10^{14}M_{\odot}$). To achieve the precision required for all our primary goals (see Analysis section, below) requires a total sample of ~ 1000 spectroscopic members, with at least ~ 50 members per system in the more massive (Virgo and Coma) subsamples. We have therefore selected the 21 clusters shown in Figure 1. It is natural and efficient to build on the existing investment in GCLASS, so we include five GCLASS clusters at $z > 1$ for our much deeper GOGREEN strategy. Additional clusters with deep IRAC data available are chosen from SpARCS (Muzzin et al. 2009, 2013; Wilson et al. 2009) and the SPT survey (Brodwin et al. 2010; Foley et al. 2011; Stalder et al. 2013). For the massive group sample, the exquisite deep optical and X–ray data in COSMOS, CDFS and SXDF make it possible to perform similar analysis on much lower mass haloes, following the GEEC2 strategy (Balogh et al. 2011). In particular the high-precision photometric-redshifts available improve target selection efficiency to a level comparable to that of the colour–selected cluster fields (Figure 4), without introducing significant bias. We have chosen nine groups in an analogous way to GEEC2, at the higher redshift range $1.0 < z < 1.5$.

Observing strategy: GOGREEN is designed to extend the GCLASS and GEEC2 surveys to lower stellar masses and higher redshifts, taking advantage of the increased red sensitivity of GMOS to gain a factor ~ 5 in depth with a relatively modest increase in exposure time (executing GOGREEN with the EEV detectors would take more than five times longer, over 2300h). Galaxies will be selected based on their 3.6μm flux from our deep IRAC imaging, and their $z-$band flux from deep imaging taken as part of GOGREEN. At these redshifts, the GMOS field of view covers 2.6×2.6 Mpc and thus covers the full cluster out to the expected virial radius. With multiple masks, and optimizing the use of nod-and-shuffle spectroscopy, it is possible to obtain highly complete spectroscopy even in the dense cores of these systems, as we have demonstrated with GCLASS.

GOGREEN will observe each group or cluster with multiple masks, spread over several semesters. We will allocate ~ 15 of the faintest galaxies ($z' > 23.5$) to every mask, such that they obtain 15h of total integration time. Another 5–10 slits per mask on brighter galaxies will be different for each mask. For massive clusters in which we have little or no existing data, we will take 5 masks of 3h each, to maximize the number of brighter targets. For the groups, and for GCLASS clusters with existing spectroscopy on bright members, we will take three masks of 5h exposure, as there are fewer bright targets available. By spreading the masks over three semesters we can make adjustments between observations; for example, by replacing faint targets that have reached the desired S/N prematurely.

We have modeled our targeting strategy in detail, using the deep photometry in COSMOS and adding artificial clusters with an assumed quiescent and total stellar mass function consistent with existing data, and with a radial distribution given by an NFW profile. Figure 4 shows how we use these simulations to determine a) an efficient (z-[3.6]) colour cut for preselecting targets; b) the expected efficiency of targeting cluster members with this colour cut, and c) an estimate of the final sample size. In total GOGREEN will add ~ 700 confirmed cluster members to our existing data, bringing the total $1 < z < 1.5$ sample to over 1000. All Virgo-progenitor and Coma-progenitor clusters will have over 50 members each, and the groups will have over 20.

Analysis: At $1 < z < 1.5$, [3.6]μm photometry is closely correlated with stellar mass. Most of our targets have deep multicolour optical and NIR data, from which we can derive M/L, and we are committed to completing this coverage for the entire sample. Even for those clusters which

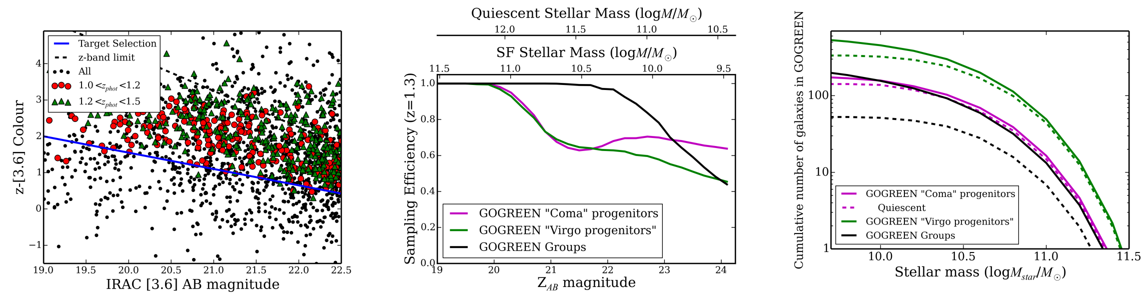


Figure 4: *Left:* (z-[3.6])as a function of [3.6] magnitude for a random subset of COSMOS data, coloured by photometric redshift. By selecting galaxies above the blue line, we reduce our field contamination by more than 50%. Mask design will be based on the $z-$band identifications, so these images must therefore reach $z_{AB} = 24.25$ (dashed, black line). *Middle:* The resulting fraction of cluster members as a function of magnitude, within 1.0 Mpc of a $z = 1.0$ cluster. For the groups, we use a photo-z preselection to improve the efficiency to the level shown here. *Right:* The estimated cumulative number of spectroscopic members in each halo mass bin and redshift range, including spectroscopy in hand (~ 200 bright galaxies in five GCLASS clusters).

currently lack these data, we have shown (Muzzin et al. 2012) that corrections for M/L based on D4000 are sufficient to obtain masses to within a factor ~ 2 of those derived from SED–fitting. This requires D4000 to be measured to within 20% precision (corresponding to S/N$\sim$0.7 per pixel), which will be achievable for every galaxy for which we can get a redshift.

To measure the quiescent fraction we need to classify our galaxies. From the spectra alone we can use the [OII] emission line and D4000 break to identify star–forming galaxies (Muzzin et al. 2012). Averaged over large enough samples, [OII] is a good star formation indicator at these redshifts (e.g. Hayashi et al. 2013). Although LINER emission can be important in red galaxies (Yan et al. 2009; Yan & Blanton 2012) this can be mitigated with colour cuts (Gilbank et al. 2011). A complementary way to classify galaxies is from the “UVJ” colour–colour diagram, which does an excellent job of separating dusty star–forming galaxies from truly passive galaxies (e.g. Muzzin et al. 2013, Mok et al. 2013, 2014). This requires deep R/I/J/K imaging, which we have for most clusters in our sample. For the remainder we will apply to CFHT, Subaru, VLT and Magellan.

Good age estimates can be obtained from absorption lines of Hδ, Calcium K and G-band (Muzzin et al. 2014). While these lines cannot generally be measured reliably from individual spectra (they have $S/N \sim 3$ by definition, as outlined in the Technical case), we only need to stack ~ 40 galaxies to obtain $S/N > 20$, sufficient to derive meaningful ages (e.g. Conroy et al. 2014). Our sample size therefore allows us to calculate average spectra in bins of stellar mass, radius and halo mass, and constrain the luminosity–weighted age to within ~ 20 per cent (Demarco et al. 2010; Mok et al. 2014; Muzzin et al. 2014). The most massive galaxies in these clusters are bright, $K = 20$ (AB) for even the most distant clusters (Lidman et al. 2012). We will include some of the brightest galaxies on all masks for a given cluster, to achieve $S/N > 20$ per spectral feature, allowing us to measure age-sensitive features for these individual galaxies, even for the highest-redshift systems.

For the dynamical analysis, we will have > 50 confirmed members in all Virgo- and Coma-progenitor clusters, sufficient to obtain unbiased estimates of total masses from their velocity dispersions (Biviano et al. 2006). While the massive groups will have “only” 20 members per system, this is still impressive for such low halo masses, and the attendant biases in mass estimation are not large, and can be corrected for (Balogh et al. in prep). More accurate, precise and detailed dynamics can be measured from stacked samples. For example, the 500 cluster members from our "Virgo-progenitor" sample are sufficient to constrain both the average total mass radial profile $M(r)$, and also the velocity anisotropy profile $\beta(r)$ of their member galaxies. Importantly, the sample size will be large enough to do this separately for the passive and star-forming populations, which are known to have different dynamics. We will achieve this using the MAMPOSSt technique (Mamon et al. 2013, Biviano et al. 2013) which breaks the intrinsic degeneracy between $M(r)$ and $\beta(r)$ in the Jeans equation. We will combine this analysis with the complementary caustic technique (Diaferio & Geller 1997), to construct solutions that are independent of assumptions about dynamical equilibrium.

Finally we note that this project can not be done with photometric redshifts only. This is obvious for the dynamics, substructure, and stellar population goals. In principle the stellar mass function and quenched fraction can be estimated from good-quality photo-z. However, even photo-z of COSMOS quality still require statistical background subtraction, which results in a large *and systematic* uncertainty for low-mass haloes (which are all that exist in such deep but narrow surveys) at the depths of interest here (Balogh et al. in prep). The problem is less severe for massive clusters but, for individual systems like this, spectroscopy is not that much more expensive, while providing a lot more information. Moreover, for these depths and spectral types photo-z are not well calibrated; in fact, providing such a calibration will be an important outcome of GOGREEN.

Technical Description

As with GCLASS, we will use the R150 grating, with a dispersion of 1.9Å/pixel. With a red blocking filter (G0307 in the North and G0331 in the South) this limits the spectrum to ~ 2250 pixels, allowing us to stack at least two tiers of spectra per mask while still assuring detection of [OII]–Hδ for all galaxies at $0.65 < z < 1.5$. In order to reliably measure a redshift from features near the 4000Å break, spectra must have sufficient signal-to-noise at $\sim$ 4200Å rest frame. Our aim is to measure redshifts for even the reddest galaxies with $z'_{AB} = 24.25$ ($I_{AB} = 25$, [3.6]μm< 22.5 at $z = 1$). The attached ITC calculation shows the result of a 15h exposure under average conditions. We achieve S/N=0.6 per pixel at the red edge of the 4000Å break, or 2.7 integrated over a 20Å absorption line. Balogh and Muzzin have confirmed, independently from GEEC2 and GCLASS, that this is a well-defined minimum value for which it is possible to obtain an absorption–line redshift. GOGREEN will be helped by the fact that the red sensitivity allows other absorption features (such as the G-band) to provide signal for the cross correlation, and thus our S/N-per-pixel requirement will be lower. In better conditions (50% CC and 20% IQ) our S/N will double, and priority visitor mode will help us to take advantage of this by observing when conditions are at their best. As described in the Experimental Design section, we will split our observations over multiple masks; the number of masks and integration time on each will vary, but the total amount of integration on each cluster or group is 15h. Given overheads associated with nod-and-shuffle spectroscopy (30%, based on hundreds of hours of experience), we require 19.5h per system.

Thirteen of our targets require deep $z-$band images that reach a 10σ extended source limit of $z'_{AB} = 24.25$ ($I_{AB} = 25.0$) in order to securely select targets and design masks. As shown on the attached ITC page, in average conditions this requires 1.5h exposure with the Hamamatsu CCDs, or 6090s with overheads (assuming 900s exposures with 2x2 binning). In some cases better conditions are requested in order to find suitable guide stars. For the northern targets it is not sensible to wait for the Hamamatsu detectors to obtain the imaging, as this pushes too much of the spectroscopy late in the LLP cycle. Where possible (i.e. for equatorial targets) we will obtain the imaging from the South even if the spectroscopy is planned for the North. For the two others we will take the images with the current detectors; this requires 9000s (9745 with overhead) in good conditions, as shown in the attached ITC. Because our spectroscopic targets are very faint, we would prefer to design masks from preimages using the same detectors, when possible. Therefore we also request time for short (900s+7min overhead) exposures of 13 fields to be taken with the instrument/camera that is to be used for the spectroscopy, so we can bootstrap from deep imaging taken elsewhere.

Time request and scheduling:

The total time required for GOGREEN is 409.5h for the spectroscopy (39×5h masks and 40 × 3h masks plus overheads), and another 28.8h for the imaging, for a total of 438.35h, a factor 5 faster than would be possible with the EEV chips. The clusters are distributed in RA and Declination, and we have made a detailed 6-semester plan demonstrating that it is straightforward to schedule evenly throughout the duration, with 20–60 hours per semester per telescope. Spectroscopic observations on Gemini-N would not begin until the Hamamatsu detectors are available (assumed to be 2015B), so we have focused our sample on southern and equatorial targets, with only four clusters that must be observed with Gemini-N. We can accommodate a delay of a semester or two in delivery of these detectors, by shifting observation of some equatorial targets to the South, and increasing the number of hours per semester required in the final year of the programme.

Observing Mode

Our team is eager to participate in priority visitor mode, and we have identified several members to carry out the observations (see Management Plan). However we request that the pre-imaging be carried out in queue mode so it can be obtained as early as possible and in sufficiently good conditions, to enable the rest of the program.

Management Plan

As PI, Michael Balogh assumes overall responsibility for making sure tasks are done on time and resources are appropriately allocated. Internal catalogue distribution will be done via a private wiki page, and Balogh will distribute quarterly updates to the collaboration via an online newsletter. During the data acquisition phase, monthly telecons will be held among members of the Data Acquisition and Reduction (DAR) team (see below), though all team members will be welcome to join. There will also be one general, collaboration-wide telecon 4–6 weeks in advance of each annual progress review, and Balogh will be responsible for preparing the review material. Balogh and Wilson will apply for funds to subsidize at least one face-to-face meeting of the entire collaboration, which would be held close to the anniversary of the survey completion. The DAR team is made up of ten people, all of whom are experienced GMOS users, and including some of the most active members of the GCLASS and GEEC2 surveys. In order to ensure the data processing is completed on time, with sufficient redundancy to avoid bottlenecks, specific tasks have been allocated as shown in Table 1.

Time Commitments: Members of our collaboration will participate in GOGREEN in different ways. The time commitments of the DAR team are shown in the left columns of Table 2. Team members identified in the right columns will lead the core papers that address the primary science goals described in this proposal. The analysis tools and techniques required for many of these papers are already in hand, and we have identified ~ 8 papers that can be published within the first year after survey completion, based solely on GOGREEN data.

Finally, the full advantage of this homogeneous data set will be exploited when the data are compared carefully with lower-redshift data and theoretical models. The collaborators shown in the bottom of Table 2 have committed to making their data/models available on short timescales to all Collaboration members, for the purpose of GOGREEN analysis and interpretation.

Task	Team	Timeline	Input and Output
Preimaging	**Muzzin** Balogh, Just, Gilbank	Catalogues complete 3 days after data acquisition.	Requires: IRAC catalogues Produces: Reduced, calibrated preimages; photometry catalogue combined with IRAC
Phase 2	**Balogh** Muzzin, Wilson, Lidman	Mask design complete within 1 week of preimage reduction.	Requires: Preimaging catalogues Produces: Phase 2 OT, MOS mask design
Observing	**Wilson** Muzzin, Nantais, Demarco, Lidman	One 2 week run per semester.	Requires: Phase 2 Produces: MOS Data
Spec DR	**Muzzin** Balogh, Gilbank, Wilson, Lidman, Cooper	Provide to the team within 1 month of observation.	Requires: MOS Data Produces: Reduced 1D and 2D MOS. Redshifts (2 independent), [OII], D4000, selection function.
Cluster Dynamics	**Biviano** Balogh, Muzzin	Within 3 months of completion of data collection on a cluster	Requires: Spec DR, imaging catalogues Produces: preliminary σ, R_{200}, membership
Galaxies	**McGee** Muzzin	Provide to the team within 3 months of data collection on a cluster	Requires: Reduced spectra, preimaging catalogues, any available imaging. Produces: M_{star}, SFR, rest-frame colours.
Public Release	**Balogh** Muzzin, Wilson	12 months following survey completion	Requires: Reduced spectra and catalogues Produces: Public webpage with documentation, catalogues, data and scripts

Table 1: The division of labour and responsibilities amongst the DAR team. Leaders of each portion are identified in **boldface**.

Data Acquisition Phase 2014B-2017B		Science Analysis and first publications 2018-2019	
Hours per month	Names	Hours per month	Names
30-40	Balogh, Muzzin, Wilson	30-40	Balogh, Biviano, Gilbank, Muzzin, Wilson
15-30	Demarco, Just, Nantais	15-30	Cooper, Just, Lambas, McGee, Noble, Poggianti, Rudnick, van der Burg, Webb, Willis, Yee
5-15	Cooper, Gilbank, Lidman, McGee	5-15	Bower, Conroy, De Lucia, McCarthy, Wetzel

Name	Product	Name	Product
Finoguenov, Willis	XMM-LSS	Wilson, Muzzin	GCLASS
Balogh, McGee	GEEC1, GEEC2	Hoekstra, van der Burg	MeNEACS, CCCP
Yee, Ellingson	RCS	Wetzel, Tinker	Halo models
De Lucia	Semi-analytics	Bower, McCarthy	Hydrodynamic simulations
Just, Poggianti, Rudnick, Zaritsky	EDisCS	Poggianti	WINGS

Table 2: *Upper:* Time commitments during the data acquisition and science analysis phases of GOGREEN. *Lower:* Co-Is who will contribute to the interpretation through comparison to other data or models, as indicated.

Added Value

It is our objective to make the GOGREEN survey a community resource, so we plan to release reduced data and catalogues of derived quantities within 12 months of the end of the survey. In addition, we will include the existing GCLASS and GEEC2 data in the release, in a homogeneous way, providing the international community with ~ 37 well studied clusters at $0.8 < z < 1.5$ that will be the go-to sample for follow-up and calibration work for many years to come. We will also make available key custom data reduction and analysis scripts.

Justify Target Duplications

Five of the targets in this proposal have been observed with GMOS previously, as part of the GCLASS survey. GCLASS targetted galaxies > 1 mag brighter (and, at the faint limit, significantly bluer) than the galaxies that will be observed for GOGREEN. Of course the brighter galaxies obtained previously are included in our final sample.

Publications

Members of our team have collectively written over 1000 papers that are directly relevant to this proposal, including 14 from GCLASS and GEEC2. In order to reserve valuable proposal space we reluctantly omit the list, here. It is available from ADS at `http://tinyurl.com/gogreenpubs`.

Use of Other Facilities or Resources

We are applying for HST Cycle 22 observations of some GCLASS clusters.

Previous Use of Gemini

Reference	Allocation	% Useful	Status of previous data
GN-2014A-Q-40	30h	0	Continuation of GN-2013A-Q-84: no data taken yet.
GS-2013B-Q-34	4h	100	F2 observations of central galaxies in GEEC2. Reduced.
GN-2013A-Q-84	51 h	75	3/4 masks taken; data reduced, awaiting completion of program.
GS-2012B-Q-36	22 h	0	No data taken

ITC Examples

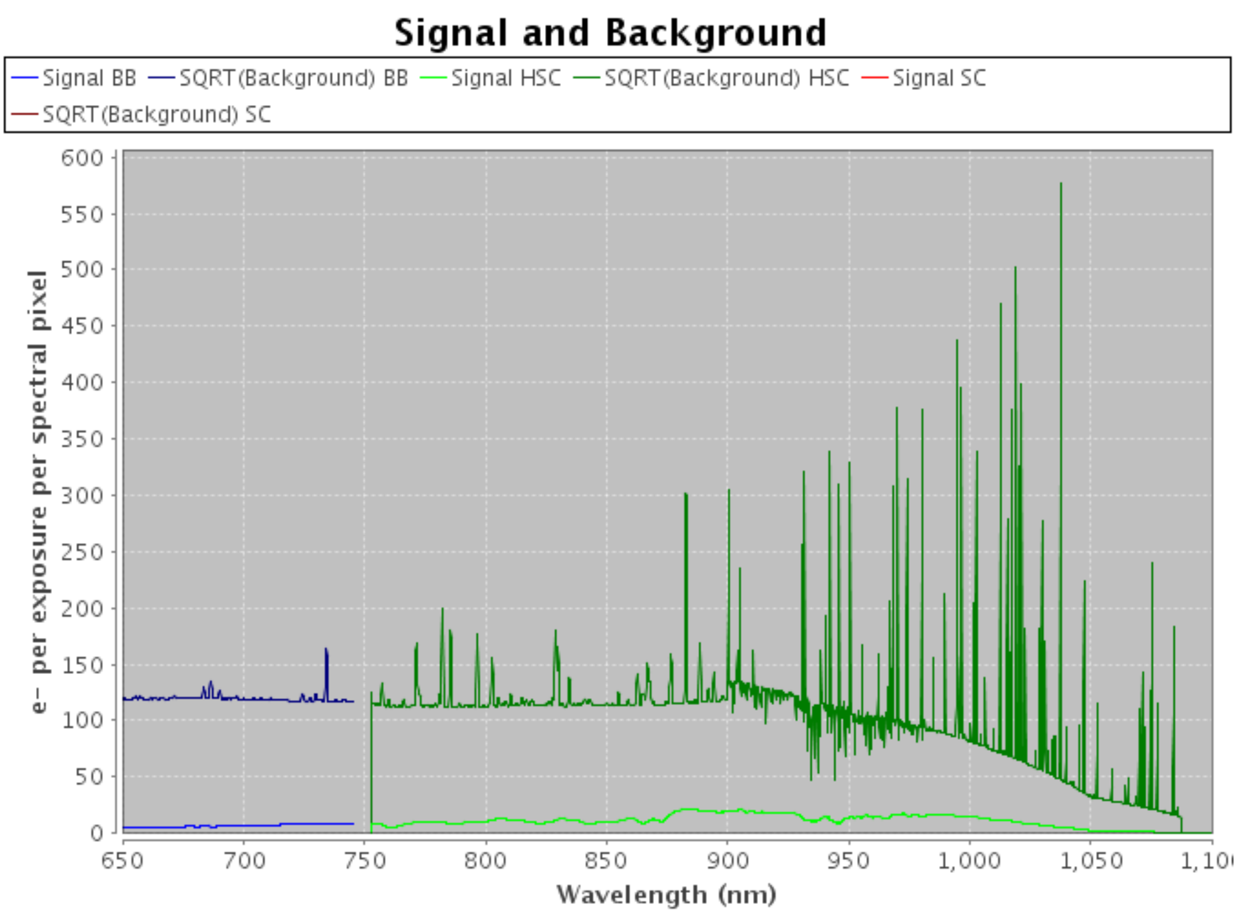
Gemini Integration Time Calculator
GMOS version 5.0

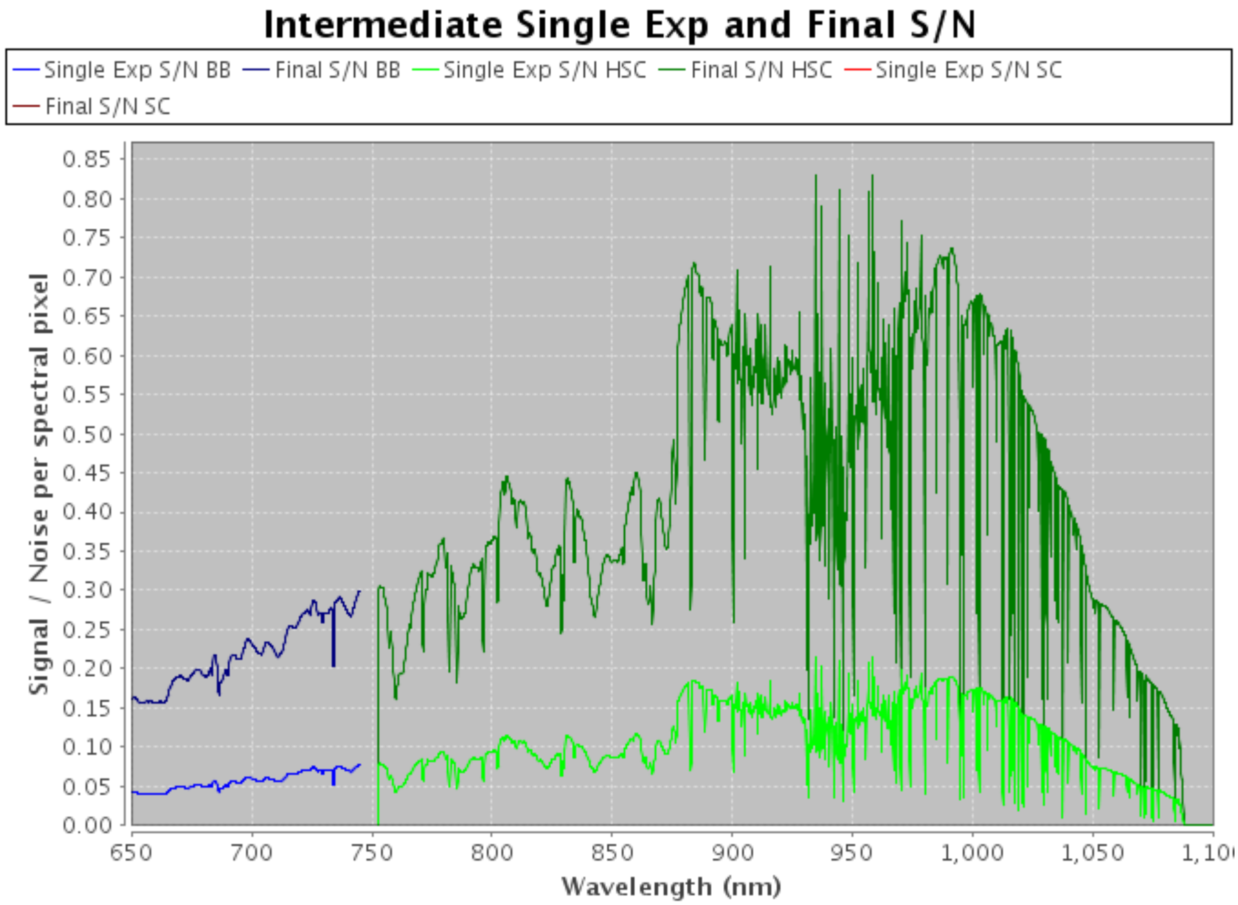
Click here for help with the results page.
Read noise: 4.1
software aperture extent along slit = 1.27 arcsec
fraction of source flux in aperture = 0.71
derived image size(FWHM) for a point source = 0.90arcsec

Sky subtraction aperture = 1.0 times the software aperture.

Requested total integration time = 54000.00 secs, of which 54000.00 secs is on source.

Click here for ASCII signal spectrum.
Click here for ASCII background spectrum.
Click here for Single Exposure S/N ASCII data.
Click here for Final S/N ASCII data.





Output:
- Spectra plotted over range 0.65 - 1.1

Input Parameters:
Instrument: GMOS-S

Source spatial profile, brightness, and spectral distribution:
The z = 1.2 point source is a 25.0 ABmag elliptical-galaxy in the I band.

Instrument configuration:
Optical Components:
- Filter: rg610
- Fixed Optics
- Grating Optics: R150_G5306
- Detector - Hamamatsu array
- Focal Plane Mask: slit1.0

Central Wavelength: 950.0 nm
Spatial Binning: 1
Spectral Binning: 1
Pixel Size in Spatial Direction: 0.080778arcsec
Pixel Size in Spectral Direction: 0.193nm

Telescope configuration:
- silver mirror coating.
- side looking port.
- wavefront sensor: oiwfs

Observing Conditions:
- Image Quality: 70.00%
- Sky Transparency (cloud cover): 70.00%
- Sky transparency (water vapour): 100.00%
- Sky background: 80.00%
- Airmass: 1.50

Frequency of occurrence of these conditions: 39.19%

Calculation and analysis methods:
- mode: spectroscopy
- Calculation of S/N ratio with 30 exposures of 1800.00 secs, and 100.00 % of them were on source.
- Analysis performed for aperture that gives 'optimum' S/N and a sky aperture that is 1.00 times the target aperture.

Gemini Integration Time Calculator
GMOS version 5.0

Click here for help with the results page.
software aperture diameter = 0.94 arcsec
fraction of source flux in aperture = 0.61
enclosed pixels = 107.26

derived image size for source = 0.80

Sky subtraction aperture = 10.0 times the software aperture.

Read noise: 4.1

S/N for BB:

Contributions to total noise (e-) in aperture (per exposure):
Source noise = 96.93
Background noise = 2441.03
Dark current noise = 3.49
Readout noise = 42.46

Total noise per exposure = 2443.32
Total signal per exposure = 9396.15

Derived number of exposures = 8 , of which 8 are on source.
Taking 8 exposures, the effective S/N for the whole observation is 10.37 (including sky subtraction)

Required total integration time is 4800.00 secs, of which 4800.00 secs is on source.

The peak pixel signal + background is 55668.

S/N for HSC:

Contributions to total noise (e-) in aperture (per exposure):
Source noise = 91
Background noise = 2313
Dark current noise = 3
Readout noise = 42

Total noise per exposure = 2315
Total signal per exposure = 8432

Derived number of exposures = 9 , of which 9 are on source.
Taking 9 exposures, the effective S/N for the whole observation is 10.41 (including sky subtraction)

Required total integration time is 5400.00 secs, of which 5400.00 secs is on source.

The peak pixel signal + background is 49998.

S/N for SC:

Contributions to total noise (e-) in aperture (per exposure):
Source noise = 93
Background noise = 2360
Dark current noise = 3
Readout noise = 42

Total noise per exposure = 2363
Total signal per exposure = 8770

Derived number of exposures = 8 , of which 8 are on source.
Taking 8 exposures, the effective S/N for the whole observation is 10.01 (including sky subtraction)

Required total integration time is 4800.00 secs, of which 4800.00 secs is on source.

The peak pixel signal + background is 52071.

Output:
- Spectra plotted over range 0.65 - 1.1

Input Parameters:
Instrument: GMOS-S

Source spatial profile, brightness, and spectral distribution:
The z = 1.3 extended source is a 25.0 ABmag elliptical-galaxy in the I band.

Instrument configuration:
Optical Components:
- Filter: z_G0304
- Fixed Optics
- Detector - Hamamatsu array

Spatial Binning: 1
Pixel Size in Spatial Direction: 0.080778arcsec

Telescope configuration:
- silver mirror coating.
- side looking port.
- wavefront sensor: oiwfs

Observing Conditions:
- Image Quality: 70.00%
- Sky Transparency (cloud cover): 70.00%
- Sky transparency (water vapour): 100.00%
- Sky background: 80.00%

- Airmass: 1.50

Frequency of occurrence of these conditions: 39.19%

Calculation and analysis methods:

- mode: imaging
- Calculation of integration time from a S/N ratio of 10.00 for exposures of 600.00 with 100.00 % of them were on source.
- Analysis performed for aperture that gives 'optimum' S/N and a sky aperture that is 10.00 times the target aperture.

Gemini Integration Time Calculator
GMOS version 5.0

Click here for help with the results page.
software aperture diameter = 0.94 arcsec
fraction of source flux in aperture = 0.61
enclosed pixels = 132.42

derived image size for source = 0.80

Sky subtraction aperture = 10.0 times the software aperture.

Read noise: 3.6

S/N:

Contributions to total noise (e-) in aperture (per exposure):
Source noise = 56.08
Background noise = 1147.45
Dark current noise = 3.88
Readout noise = 41.42

Total noise per exposure = 1149.58
Total signal per exposure = 3145.60

Derived number of exposures = 15 , of which 15 are on source.
Taking 15 exposures, the effective S/N for the whole observation is 10.10 (including sky subtraction)

Required total integration time is 9000.00 secs, of which 9000.00 secs is on source.

The peak pixel signal + background is 9976.

Output:
- Spectra plotted over range 0.65 - 1.1

Input Parameters:
Instrument: GMOS-N

Source spatial profile, brightness, and spectral distribution:
The z = 1.3 extended source is a 25.0 ABmag elliptical-galaxy in the I band.

Instrument configuration:
Optical Components:
- Filter: z_G0304
- Fixed Optics
- Detector - EEV legacy array

Spatial Binning: 1
Pixel Size in Spatial Direction: 0.0727arcsec

Telescope configuration:
- silver mirror coating.
- side looking port.
- wavefront sensor: oiwfs

Observing Conditions:
- Image Quality: 70.00%
- Sky Transparency (cloud cover): 50.00%
- Sky transparency (water vapour): 100.00%
- Sky background: 50.00%
- Airmass: 1.50

Frequency of occurrence of these conditions: 17.50%

Calculation and analysis methods:
- mode: imaging
- Calculation of integration time from a S/N ratio of 10.00 for exposures of 600.00 with 100.00 % of them were on source.
- Analysis performed for aperture that gives 'optimum' S/N and a sky aperture that is 10.00 times the target aperture.