Resubmission of 08B-0147

NOAO Observing Proposal *Survey proposal* **Panel:** *For office use.*
Date: September 15, 2008 **Category:** Cosmology

Normalization and scatter of the mass-temperature relation for supermassive galaxy clusters

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Abstract of Scientific Justification *(will be made publicly available for accepted proposals)*:
We propose a high-accuracy survey of the 20 most massive clusters in the northern hemisphere at $0.15 < z < 0.3$, to yield a uniform catalog of X-ray, galaxy, and dark-matter properties (from weak gravitational lensing, WL). All quantities will be determined with high S/N and low systematic errors. The major scientific goals are to (a) determine the normalization *and scatter* in the mass-temperature relation for massive clusters, which is essential for the use of clusters to constrain cosmological parameters, and (b) use the relations between WL mass, X-ray temperature, and other structural variables to validate numerical models of cluster evolution. There has to date been no cluster lensing survey with sufficiently large sample size and sufficiently low random and systematic errors to infer the intrinsic component of the M-T scatter. We expect to determine the scatter in the M-T relation to $\pm 5\%$. All targets have existing Chandra, XMM, and ASCA X-ray data, HST strong-lensing imaging, and all but two have existing good-seeing image from Subaru or scheduled observation time at MMT. Our project will complete the WL imaging and, with this proposal, obtain multiband Mosaic observations for photometric redshifts. Uniform photo-z's are essential to properly calibrate the WL data and isolate the (unlensed) cluster member galaxies.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	KP-4m	MOSA	4	darkest	Dec - Apr	Aug - Jul
2	KP-4m	MOSA	4	dark	Dec - Apr	Aug - Jul
3	KP-4m	MOSA	3	grey	Dec - Apr	Aug - Jul
4						
5						
6						

Scheduling constraints and non-usable dates *(up to four lines).*

15 of 18 target fields are in the 7-16h RA range, hence Dec-Apr are the most productive months.

Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

The abundance of galaxy clusters is a key measure of dark energy (Albrecht et al. 2006), and the properties of massive clusters provide very stringent tests of theories of gravitational collapse. We have designed a survey to obtain the most precise and accurate measures to date of galaxy-cluster projected masses, X-ray properties, and galaxy contents, to facilitate new tests of cluster models and to evaluate the suitability of galaxy clusters as a dark-energy test.

Survey summary: The targets are the 20 most massive galaxy clusters in the northern hemisphere with $0.15 < z < 0.3$, selected by X-ray temperature to have $M > 10^{15}h^{-1}M_{\odot}$. Focusing on the most massive clusters gives the most precise tests of models because it maximizes the S/N level of the observations, particularly the weak gravitational lensing (WL) mass determinations. The X-ray surveys and pointed followups are complete in this mass-redshift range, so we can select a complete sample and conduct meaningful statistical studies.

Each cluster will have X-ray data from Chandra and/or XMM, X-ray temperatures from ASCA, HST imaging of the central regions for strong-lensing features, and wide-field imaging from Subaru and/or MMT for highest-quality WL mass measurements. Almost all of these necessary data are available in public archives. This proposal is to obtain multi-color imaging of all galaxies in the cluster fields from the Mayall 4-meter, for determination of photometric redshifts that reliably identify cluster members of all types (not just red-sequence) and determine the redshift distribution of the background source galaxies in the weak-lensing study. *Uniform* photometric data is needed to execute a photo-z calibration that is stable across the survey.

The survey data products will be uniform catalogs of: X-ray properties; WL projected masses; member-galaxy catalogs (photo-z selected); and morphological information on X-ray and WL mass distributions. Many cluster catalogs and WL measurements exist, but this survey will be unique in its precise and accurate calibration of the WL masses for a sizable, fair sample. This high-quality catalog will find many scientific applications; we describe here our highest priorities.

Scatter in the M-T relation: The primary quantitative goal of our proposed survey is to carry out the first precision measurement of the normalization *and scatter* between cluster X-ray observables and the true projected mass of galaxy clusters, determined via WL. Knowledge of this scatter is essential for the use of galaxy cluster abundances to constrain dark energy with upcoming cluster surveys (Albrecht et al. 2006, Lima & Hu 2005), such as Planck, ACT (Kosowsky 2006) and SPT. Mandelbaum & Seljak 2007 show that, without knowing the size of the scatter, it is impossible to constrain σ_8 to within ~ 0.10. Past halo-abundance studies studies have had to assume a mean relation *and* scatter between halo mass and X-ray observable to extract cosmological information (*e.g.*, Ikebe et al. 2002).

Our survey will determine the mass scatter to $\pm 5\%$, assuming intrinsic scatter in $M(T_x)$ of 20% (Kravtsov et al. 2006, Stanek et al. 2006). This project will be the first to produce WL masses with measurement error below the intrinsic scatter, for a sample large and complete enough to determine the scatter. The "Experimental Design" section details the careful survey design needed to achieve the high statistical precision and low systematic contamination required for this scientific goal. Briefly, it is impossible without, first, wide-field imaging in good seeing to determine shapes of many weakly-lensed background galaxies—all but two of which are already in the Subaru archive or scheduled to be observed at MMT. Second, deep, multiband imaging from the KPNO-4m Mosaic and resultant photo-z's are needed to distinguish cluster members from WL background sources, and calibrate the distances to the latter. Third, the WL methodology must be validated to percent-level accuracy.

Cluster model validation: The mean and scatter in $M(T_x)$ are of intrinsic interest aside from their utility for cosmology. N-body+hydrodynamics models of galaxy clusters are quite advanced and make definitive, testable predictions for $M(T_x)$. Right now there are still $\sim$ 20% normalization discrepancies between scaling relations in simulations and observations (Arnaud et al. 2007, Nagai et al. 2007). This could be, for example, due to the fact that ICM in real clusters has non-thermal pressure support, neglected in hydrostatic estimates of the mass. Models predict that the X-ray "Y_x parameter" (Kravtsov et al. 2006) has very low scatter w.r.t. mass even in unrelaxed clusters, but WL is the only path to accurate mass estimates for the unrelaxed clusters. Hence there is substantial motivation for highest-quality data on a fairly-selected sample of clusters.

Our cluster survey will enable many new tests of models: first we will determine the M-T_x scatter, but also joint distributions of other observables can be predicted and measured in our data—concentration parameters and multipole moments of the X-ray and dark-matter distributions, which are measurable at useful S/N in these most massive clusters (without stacking). We will measure projected ellipticities, which when compared against the predictions from N-body simulations (e.g., Allgood et al. 2006; Flores et al. 2007), will constrain the effects of rounding due to baryonic physics (Kazantzidis et al. 2006).

An important subtlety is that most models refer to cluster 3d virial masses whereas WL measures a 2d projected mass distribution, which includes the cluster virial core, nonvirialized structure local to the cluster (e.g. Metzler et al. 2000), and distant large-scale structure randomly projected along the line of sight (e.g., Hoekstra 2003). The latter two sources of "projection noise" in the 2d WL masses depend, however, on less complicated physics, and can be constrained with N-body simulations at least as well as the baryonic processes producing the virial X-ray emission. Hence this subtlety does not degrade the power of our survey to validate cluster models. Indeed since cluster surveys are conducted either by baryonic properties (X-ray and SZ) or WL signals, it is more crucial to validate theoretical predictions of these than virial mass. Nonetheless we have a new $1/h$ Gpc N-body simulation that can be used to determine the projection effects with much greater statistical power than before, so we can remove their contribution and estimate the intrinsic scatter in virial $M(T_x)$ to high precision.

Cluster galaxy properties: This photo-z survey will produce luminosity-function data on target clusters similar in depth to the SDSS data on low-redshift clusters. Red-sequence studies have detailed the properties of early-type galaxies in moderate-redshift clusters, but photo-z data will allow type-dependent LFs for these clusters to the virial radius. These LF's will extend at least 4–5 mag below $M^\star$ for all 20 clusters, allowing us to determine whether observed trends in faint-end slope with cluster richness and radius at $z \approx 0$ (e.g. Barkhouse et al. 2007) were in place at $z \approx 0.3$.

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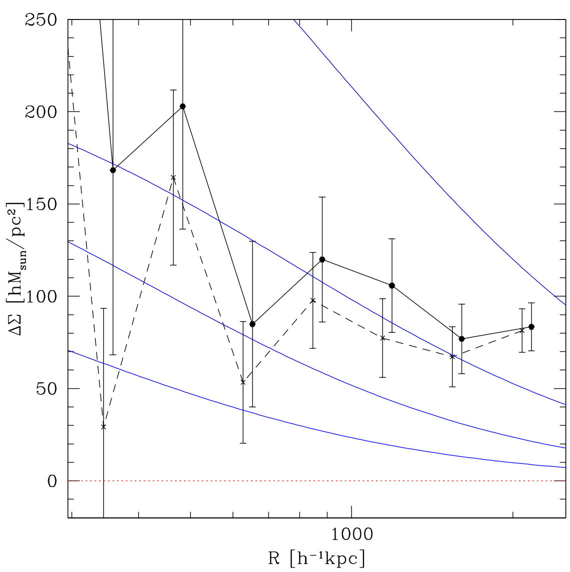

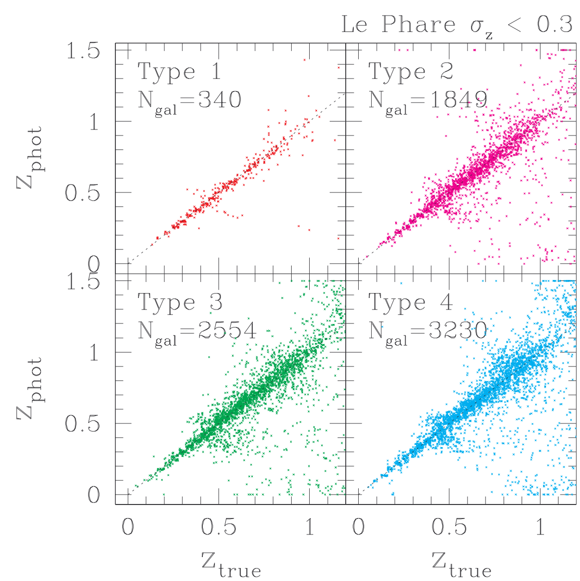

Figure 1: **Left:** Preliminary analysis of Abell 2219 based on KPNO photometry obtained May/Jun 2008 and Subaru archival data. This figure plots the azimuthally-averaged weak lensing mass profile $\Delta\Sigma$, with (solid points) and without (crosses) a crude photo-z based on 5-band photometry. The solid (blue) curves are prediction for NFW profiles with masses, from top, $\log[M_{180b}/h^{-1}M_\odot]$ = 15.5, 15.0, 14.5, and 14.0. This result is consistent with that obtained by Hoekstra (2007). Contamination from cluster member galaxies significantly degrades signal below 2 Mpc/h; NFW mass accuracy is expected to improve with the use of true photo-z. **Right:** Simulation of comparison of true redshift to photo-z, estimated using LePhare photo-z code (Ilbert et al., 2006) with our chosen filters and limiting magnitudes. Type 1 represents the red elliptical galaxies, while Type 4 represents the blue star-forming galaxies, and Types 2 and 3 are intermediate types. The simulated source sample is dominated by faint blue galaxies with $0.8 < z < 1.2$.

Experimental Design *Describe the survey experimental design and the observations planned in detail. Justify choice of telescope, instrument, and sensitivity goals in terms of the survey science goals. A key part of the survey proposal process is to justify the total duration of the program both in terms of the number of nights and the number and distribution of observing runs required. Please show explicitly how on-target exposure time, setup, and calibration requirements determine these parameters. Please do not include any allowance for bad weather. Based on a clear understanding of your observational strategy as outlined in this section, we will evaluate the need for augmenting the allocation to allow for bad weather.*

Our survey is carefully designed to allow us to meet our goal of measuring the full $M(T_x)$ relation, including scatter. Recently published WL cluster studies (*e.g.*, Bardeau et al. 2007, Mahdavi et al. 2007) demonstrate that our overall methodology is reasonable, but that a new survey is required: Bardeau et al. 2007 state explicitly that their sample is too small, with uncertainties in individual masses that are too large to determine intrinsic scatter. Our project will achieve our goals because of (a) reduced sample variance due to the large sample size, (b) strict T_x selection to have a fair sample, (c) systematic-error control by using verified high-precision shear measurement methods and accurate source and cluster-galaxy photo-z's, and (d) the reduction of measurement errors below the intrinsic scatter using the best-available shear data from the Subaru Suprime-cam for the most massive clusters (best possible S/N).

First, we use the most massive clusters to maximize S/N. Second, we require very low *systematic* errors in WL measurement. Understanding of the technical aspects of WL has significantly improved even in the past 2 years, bringing the field to of order 1% accuracy, as demonstrated by the recent STEP2 results (Massey et al. 2007). Co-I's on this proposal have developed *three* of the best-performing WL pipelines in the STEP tests. Many lensing-based cluster mass estimates have large calibration uncertainties ($\sim 20\%$) due to ignorance of the source dN/dz; the multi-band photo-z data from KPNO will reduce the calibration uncertainty by a factor of 10. The photo-z data will also allow us to reliably identify cluster galaxies, which would otherwise contaminate the source sample and suppress the lensing signal in the inner cluster regions at the $\sim 30\%$ level (Limousin et al. 2006, and see the left panel of Fig. 1 for evidence that this is true for our analysis as well). In short, without these homogeneous photo-z data, our goal of precisely determining the $M(T_x)$ relation will be impossible due to systematic errors that are an order of magnitude too high.

Sample selection and size: Given a sample of 20 T_x-selected clusters, we can calculate expected statistical errors on projected 2d masses. Our Fisher matrix analysis, incorporating Subaru WL data alone (no strong lensing data), suggests that with $M_{180\overline{\rho}} \sim 10^{15}h^{-1}M_{sun}$ we can achieve a statistical error on the projected cluster mass of 5% per cluster. This measurement error is far below the other sources of scatter discussed in the scientific justification (which total $\sim 40\%$ scatter when going from X-ray temperature to 3d halo mass to 2d projected mass). If the scatter and noise are drawn from lognormal distributions, then the ensemble mean value of M can be determined to 9%, and the total scatter in the 2d mass at fixed X-ray temperature can be determined to within 5%. When combined with the N-body simulations to determine the scatter due to large-scale structure along the line of sight and the projection from 2d to 3d, we can subtract off those contributions to determine the scatter in the $M(T_x)$ relation to high precision (i.e. 5% out of an expected 20%, or one part in four). We emphasize that this is only possible because our survey design *maximizes* statistical S/N and *minimizes* sources of systematic error.

The X-ray temperature is more highly correlated with the cluster mass than the X-ray luminosity; we require $T_x > 6.5$ keV to obtain virial masses $> 10^{15}h^{-1}M_\odot$ (Dahle et al. 2002, Smith et al. 2005). A large, relatively unbiased catalog of clusters with temperatures from ASCA (Horner 2001) is the basis for our selection, with corrections for point-source contamination and cooling cores from Chandra data (Cavagnolo & Donahue 2007). We choose the redshift range $0.15 < z < 0.3$:

at lower redshift, the lensing efficiency is low, and for $z > 0.3$, the X-ray measurements would have insufficient S/N for detailed comparisons of the temperature and shear maps. We also require dec $> -20°$ and r-band extinction < 0.3 mag to facilitate ground-based observations and photo-z determination. Our selection criteria lead to an unbiased sample of supermassive clusters, because we do not eliminate complex or merging systems.

Photo-z calibration: Besides the 20 clusters (19 targets, one of which is a double cluster that will fit in a single pointing), we must also observe 2 photo-z calibration fields, the DEEP2 Extended Groth Strip (EGS) and 02h30m+00 00 (02h) in $Cg'r'i'z'$. In the DEEP2 02h field, a single pointing can image up to ~ 2700 galaxies with high-quality spectroscopic redshifts (spectro-z). This would suffice for photo-z calibration, except that DEEP2 has a color cut that limits its use to the redshift range $0.7 < z < 1.2$. We will mitigate the effects of this color cut in two ways: first, by utilizing 1200 DEEP2 EGS redshifts, which are approximately flux-limited to $R < 24$, and should fill in the $z < 0.7$ region; second, by using ~ 1000 Prism Multi-object Survey (PRIMUS) redshifts at $R < 23.3$, which complements the color cut in the DEEP2 02h field.

Required exposure depths: We have used the Le Phare photo-z code (Ilbert et al. 2006) to simulate a realistic photo-z sample given our exposure times and limiting magnitudes in each band (see observing run details) with the COMBO-17 spectral type-dependent R-band luminosity function (Wolf et al. 2003). Our figure of merit has three parts: how well we can determine the critical parameter for lensing, $\langle 1/\Sigma_c \rangle$, with the photometric redshifts; the fractional contamination of our source sample by cluster member galaxies; and how many source galaxies have usable photometric redshifts. We have found that our limiting magnitudes provide photo-z accuracy that reduces contamination from cluster member galaxies to the 2–3% level at the minimum scale used for lensing; reduces redshift-related calibration error to $< 1\%$; and provides photo-z's for 60–70% of sources, giving a usable source number density of ~ 20 arcmin^{-2} (see Fig 1, right panel).

Observing Runs Requested for this Project

Semester	Telescope	Instrument	# of Nights	Moon	Acceptable Months
2009A	KPNO-4m	MOSAIC	2	darkest	Feb-Jul
2009A	KPNO-4m	MOSAIC	2	dark	Feb-Jul
2009A	KPNO-4m	MOSAIC	2	grey	Feb-Jul
2009B	KPNO-4m	MOSAIC	2	darkest	Aug-Jan
2009B	KPNO-4m	MOSAIC	2	dark	Aug-Jan
2009B	KPNO-4m	MOSAIC	1	grey	Aug-Jan

Management Plan *Describe the overall organizational plan for conducting the proposed survey, including data reduction and analysis, preparation of survey deliverables, and staffing requirements. The roles and anticipated levels of participation of the survey team members should be discussed. You may also wish to detail external sources of support that will be used in the program. Please detail any use of non-NOAO observational facilities that are required to achieve the overall goals of the survey program.*

The survey reduction and analysis will be divided among multiple analysis teams. The weak lensing analysis team (Mandelbaum, Nakajima, Bernstein, Miyazaki, Schrabback and McLeod) will reduce the weak lensing data from Subaru and MMT, cross-checking multiple pre-existing shape measurement pipelines to assure reliable results. The X-ray data reduction will be carried out by Donahue and Cavagnolo (Chandra), and Hughes (XMM), also using pre-existing analysis pipelines, though much of the data has already been reduced, examined for quality, and analyzed (and was used for the targeting). The KPNO data reduction and photo-z determination will be carried out by Mandelbaum, Nakajima, and Padmanabhan. Simulation work to produce theoretical predictions will be carried out by Kravtsov using pre-existing simulations. Strong lensing analysis and data reduction will be carried out by Keeton, using pre-existing data reduction pipelines for ACS data (Nakajima, Schrabback) that can be modified for WFPC2. The overall coordination of the analysis efforts will be carried out by Mandelbaum and Nakajima.

Use of Other Facilities or Resources *(1) Describe how the proposed observations complement data from non-NOAO facilities. For each of these other facilities, indicate the nature of the observations (yours or those of others), and describe the importance of the observations proposed here in the context of the entire program. (2) Do you currently have a grant that would provide resources to support the data processing, analysis, and publication of the observations proposed here?"*

The NOAO photo-z data proposed herein will be supplemented by single-band wide-field imaging with seeing $0\farcs9$ or better for WL purposes. Suitable data is publicly available in the Subaru archive for about half of the cluster samples; most of the rest are scheduled to be observed later this year (2008) or already have been observed at MMT; proposals are pending for two of the remaining clusters.

All of the target clusters have pre-existing Chandra and/or XMM X-ray data with well-determined ASCA temperatures, and HST WFPC2 and/or ACS imaging of the cluster cores to reveal any strongly lensed features. Twelve clusters also have publicly-available Spitzer IRAC data in the cluster center that will supplement the KPNO data to get photo-z's for $z > 1$ sources.

Existing computational resources at the investigators' institutions will suffice to store and reduce these data. The code for the weak lensing data reduction and analysis, for the production of X-ray temperature maps, and for photometric redshift computation already exists.

Release of Data *Describe the timeline and mechanism for the release of data subsets, the complete dataset, and catalogs to the astronomical community.*

We plan to release images of the clusters with object catalogs approximately 6 months after observations occur. Lensing source catalogs with shape measurements and photometric redshifts will require more time, and should be released approximately one year after observations. HST data used for strong lensing are already publicly available, but we will provide reduced images one year after our KPNO observations are taken.

Previous Use of NOAO Facilities *List allocations of telescope time on facilities available through NOAO to the PI during the last 2 years for regular proposals, and at any time in the past for survey proposals (including participation of the PI as a Co-I on previous NOAO surveys), together with the current status of the data (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal. Please include original proposal semesters and ID numbers when available.*

$\boxed{\star}$ We were awarded 4 nights (May30–June2) during the 2008A semester (2008A-0356), with all nights either clear or photometric. The 26 hours worth of observation allowed us to obtain full 5-band photometry for one of the two calibration fields, as well as for 3 of the 20 cluster targets.

We have reduced the KPNO raw images to the point where we have photometric information, and are able to define color cuts that allows us to select background galaxies (defined as $z > 0.3$) at an estimated purity of $\sim 90\%$ and efficiency of $\sim$70%. These estimation are based on the calibration field with known spectroscopic redshifts. This is a huge improvement over past WL cluster studies that uses, at best, two passbands, which can only reliably identify red-sequence galaxy redshifts, and hence only give a 10 to 30% reduction in cluster member contamination (*e.g.,* Hoekstra 2007). In contrast, we have explicitly used five passbands in our preliminary analysis of Abell 2219 (Fig. 1, left panel) to achieve a much more efficient exclusion of cluster member galaxies, which with further work will be sufficient for precision weak lensing measurements. We expect to improve upon the WL mass estimate through the use of (1) true photo-z, which will further reduce cluster member galaxy contamination and improve the accuracy of WL signal normalization, and (2) better image reduction (higher source number density) on both the WL and photometry images.

Observing Run Details for Run 1: KP-4m/MOSA

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for queue and Gemini runs).*

We request darkest-time (lunar phase < 3) observation in Washington C and SDSS g' bands with the KPNO-4m telescope (Mosaic imager). For each target, we require 60 minutes of integration time split into 6 exposures in C band, and 30 minutes of integration time split into 4 exposures in g' band, to reach limiting magnitudes of 24.8 and 25.3 (point source $S/N = 10$) respectively. For these bands, we restrict observations to airmass< 1.3. 16 out of the 18 targets are observable in late December. Including integration+readout time, with 30 minutes for observing photometric standards each night, and based on our past observing run, we require 4 nights total for this observation across 2 semesters. While we request 2 nights in 2009A and 2 in 2009B it would be possible to adjust these numbers somewhat.

Instrument Configuration

Filters: C, g'	Slit:	Fiber cable:
Grating/grism:	Multislit:	Corrector:
Order:	λ_{start}:	Collimator:
Cross disperser:	λ_{end}:	Atmos. disp. corr.:

R.A. range of principal targets (hours): 0 to 16

Dec. range of principal targets (degrees): -2 to 67

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

Target Table for Run 1: KP-4m/MOSA

Obj ID	Object	α	δ	Epoch	Mag.	Filter	Exp. time	# of exp.	Lunar days	Sky	Seeing	Comment
1	ABELL0068	00:36:59.4	09:08:30.1	J2000		C	600	6	1	phot	1.1	(WL Oct 08)
2	ABELL0267	01:52:41.9	01:00:25.6	J2000		C	600	6	1	phot	1.1	WL
3	PHOTOZ02	02:30:00.0	00:00:00.0	J2000		C	600	6	1	phot	1.1	calibration field
4	ABELL0586	07:32:20.5	31:38:14.6	J2000		C	600	6	1	phot	1.1	(WL Dec 08)
5	ABELL0611	08:00:56.8	36:03:23.6	J2000		C	600	6	1	phot	1.1	WL
6	ABELL0665	08:30:45.2	65:50:34.7	J2000		C	600	6	1	phot	1.1	WL
7	ABELL0697	08:42:57.5	36:21:59.3	J2000		C	600	6	1	phot	1.1	WL
8	ABELL0773	09:17:53.4	51:43:37.3	J2000		C	600	6	1	phot	1.1	WL
9	ABELL0963	10:17:03.6	39:02:49.4	J2000		C	600	6	1	phot	1.1	WL
10	ZwCl3146	10:23:39.6	04:11:10.7	J2000		C	600	6	1	phot	1.1	(WL Dec 08)
11	ABELL1576	12:36:59.2	63:11:11.7	J2000		C	600	6	1	phot	1.1	(WL Dec 08)
12	ABELL1682	13:06:50.0	46:33:33.4	J2000		C	600	6	1	phot	1.1	(WL Dec 08)
13	ABELL1689	13:11:29.5	-01:20:27.9	J2000		C	600	6	1	phot	1.1	WL
14	ABELL1758	13:32:35.8	50:28:55.0	J2000		C	600	6	1	phot	1.1	WL
15	ABELL1763	13:35:20.0	41:00:04.1	J2000		C	600	6	1	phot	1.1	(WL prop. pending)
16	ABELL1835	14:01:02.0	02:52:42.5	J2000		C	600	6	1	phot	1.1	WL
17	ABELL1914	14:26:03.8	37:49:53.4	J2000		C	600	6	1	phot	1.1	WL
18	ABELL2111	15:39:40.4	34:25:27.3	J2000		C	600	6	1	phot	1.1	(WL prop. pending)

Target Table for Run 1: KP-4m/MOSA

Obj ID	Object	α	δ	Epoch	Mag.	Filter	Exp. time	# of exp.	Lunar days	Sky	Seeing	Comment
1	ABELL0068	00:36:59.4	09:08:30.1	J2000		g'	450	4	3	phot	1.1	(WL Oct 08)
2	ABELL0267	01:52:41.9	01:00:25.6	J2000		g'	450	4	3	phot	1.1	WL
3	PHOTOZ02	02:30:00.0	00:00:00.0	J2000		g'	450	4	3	phot	1.1	calibration field
4	ABELL0586	07:32:20.5	31:38:14.6	J2000		g'	450	4	3	phot	1.1	(WL Dec 08)
5	ABELL0611	08:00:56.8	36:03:23.6	J2000		g'	450	4	3	phot	1.1	WL
6	ABELL0665	08:30:45.2	65:50:34.7	J2000		g'	450	4	3	phot	1.1	WL
7	ABELL0697	08:42:57.5	36:21:59.3	J2000		g'	450	4	3	phot	1.1	WL
8	ABELL0773	09:17:53.4	51:43:37.3	J2000		g'	450	4	3	phot	1.1	WL
9	ABELL0963	10:17:03.6	39:02:49.4	J2000		g'	450	4	3	phot	1.1	WL
10	ZwCl3146	10:23:39.6	04:11:10.7	J2000		g'	450	4	3	phot	1.1	(WL Dec 08)
11	ABELL1576	12:36:59.2	63:11:11.7	J2000		g'	450	4	3	phot	1.1	(WL Dec 08)
12	ABELL1682	13:06:50.0	46:33:33.4	J2000		g'	450	4	3	phot	1.1	(WL Dec 08)
13	ABELL1689	13:11:29.5	-01:20:27.9	J2000		g'	450	4	3	phot	1.1	WL
14	ABELL1758	13:32:35.8	50:28:55.0	J2000		g'	450	4	3	phot	1.1	WL
15	ABELL1763	13:35:20.0	41:00:04.1	J2000		g'	450	4	3	phot	1.1	(WL prop. pending)
16	ABELL1835	14:01:02.0	02:52:42.5	J2000		g'	450	4	3	phot	1.1	WL
17	ABELL1914	14:26:03.8	37:49:53.4	J2000		g'	450	4	3	phot	1.1	WL
18	ABELL2111	15:39:40.4	34:25:27.3	J2000		g'	450	4	3	phot	1.1	(WL prop. pending)

Observing Run Details for Run 2: KP-4m/MOSA

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for queue and Gemini runs).*

We request dark-time (lunar phase < 7) observation in the SDSS r' and i' bands with the KPNO-4m telescope (Mosaic imager). For each target, we require 30 minutes of integration time split into 4 exposures in r' band; and 60 minutes of integration time split into 6 exposures in i' band. We can then expect to reach a limiting magnitude of 24.8 in r' and 24.7 in i' (point source $S/N = 10$). For these bands, we restrict observations to airmass< 1.6. Including integration+readout time, with 30 minutes for observing photometric standards each night, we request 2 nights of observation in S09A and 2 nights in S09B. There is some freedom to adjust the allocation between the two semesters, as discussed in the description for observing run 1.

Instrument Configuration

Filters: r', i'	Slit:	Fiber cable:
Grating/grism:	Multislit:	Corrector:
Order:	λ_{start}:	Collimator:
Cross disperser:	λ_{end}:	Atmos. disp. corr.:

R.A. range of principal targets (hours): 0 to 16

Dec. range of principal targets (degrees): -2 to 67

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

Target Table for Run 2: KP-4m/MOSA

Obj ID	Object	α	δ	Epoch	Mag.	Filter	Exp. time	# of exp.	Lunar days	Sky	Seeing	Comment
1	ABELL0068	00:36:59.4	09:08:30.1	J2000		r'	450	4	5	phot	1.1	(WL Oct 08)
2	ABELL0267	01:52:41.9	01:00:25.6	J2000		r'	450	4	5	phot	1.1	WL
3	PHOTOZ02	02:30:00.0	00:00:00.0	J2000		r'	450	4	5	phot	1.1	calibration field
4	ABELL0586	07:32:20.5	31:38:14.6	J2000		r'	450	4	5	phot	1.1	(WL Dec 08)
5	ABELL0611	08:00:56.8	36:03:23.6	J2000		r'	450	4	5	phot	1.1	WL
6	ABELL0665	08:30:45.2	65:50:34.7	J2000		r'	450	4	5	phot	1.1	WL
7	ABELL0697	08:42:57.5	36:21:59.3	J2000		r'	450	4	5	phot	1.1	WL
8	ABELL0773	09:17:53.4	51:43:37.3	J2000		r'	450	4	5	phot	1.1	WL
9	ABELL0963	10:17:03.6	39:02:49.4	J2000		r'	450	4	5	phot	1.1	WL
10	ZwCl3146	10:23:39.6	04:11:10.7	J2000		r'	450	4	5	phot	1.1	(WL Dec 08)
11	ABELL1576	12:36:59.2	63:11:11.7	J2000		r'	450	4	5	phot	1.1	(WL Dec 08)
12	ABELL1682	13:06:50.0	46:33:33.4	J2000		r'	450	4	5	phot	1.1	(WL Dec 08)
13	ABELL1689	13:11:29.5	-01:20:27.9	J2000		r'	450	4	5	phot	1.1	WL
14	ABELL1758	13:32:35.8	50:28:55.0	J2000		r'	450	4	5	phot	1.1	WL
15	ABELL1763	13:35:20.0	41:00:04.1	J2000		r'	450	4	5	phot	1.1	(WL prop. pending)
16	ABELL1835	14:01:02.0	02:52:42.5	J2000		r'	450	4	5	phot	1.1	WL
17	ABELL1914	14:26:03.8	37:49:53.4	J2000		r'	450	4	5	phot	1.1	WL
18	ABELL2111	15:39:40.4	34:25:27.3	J2000		r'	450	4	5	phot	1.1	(WL prop. pending)

Target Table for Run 2: KP-4m/MOSA

Obj ID	Object	α	δ	Epoch	Mag.	Filter	Exp. time	# of exp.	Lunar days	Sky	Seeing	Comment
1	ABELL0068	00:36:59.4	09:08:30.1	J2000		i'	600	6	5	phot	1.1	(WL Oct 08)
2	ABELL0267	01:52:41.9	01:00:25.6	J2000		i'	600	6	5	phot	1.1	WL
3	PHOTOZ02	02:30:00.0	00:00:00.0	J2000		i'	600	6	5	phot	1.1	calibration field
4	ABELL0586	07:32:20.5	31:38:14.6	J2000		i'	600	6	5	phot	1.1	(WL Dec 08)
5	ABELL0611	08:00:56.8	36:03:23.6	J2000		i'	600	6	5	phot	1.1	WL
6	ABELL0665	08:30:45.2	65:50:34.7	J2000		i'	600	6	5	phot	1.1	WL
7	ABELL0697	08:42:57.5	36:21:59.3	J2000		i'	600	6	5	phot	1.1	WL
8	ABELL0773	09:17:53.4	51:43:37.3	J2000		i'	600	6	5	phot	1.1	WL
9	ABELL0963	10:17:03.6	39:02:49.4	J2000		i'	600	6	5	phot	1.1	WL
10	ZwCl3146	10:23:39.6	04:11:10.7	J2000		i'	600	6	5	phot	1.1	(WL Dec 08)
11	ABELL1576	12:36:59.2	63:11:11.7	J2000		i'	600	6	5	phot	1.1	(WL Dec 08)
12	ABELL1682	13:06:50.0	46:33:33.4	J2000		i'	600	6	5	phot	1.1	(WL Dec 08)
13	ABELL1689	13:11:29.5	-01:20:27.9	J2000		i'	600	6	5	phot	1.1	WL
14	ABELL1758	13:32:35.8	50:28:55.0	J2000		i'	600	6	5	phot	1.1	WL
15	ABELL1763	13:35:20.0	41:00:04.1	J2000		i'	600	6	5	phot	1.1	(WL prop. pending)
16	ABELL1835	14:01:02.0	02:52:42.5	J2000		i'	600	6	5	phot	1.1	WL
17	ABELL1914	14:26:03.8	37:49:53.4	J2000		i'	600	6	5	phot	1.1	WL
18	ABELL2111	15:39:40.4	34:25:27.3	J2000		i'	600	6	5	phot	1.1	(WL prop. pending)

Observing Run Details for Run 3: KP-4m/MOSA

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for queue and Gemini runs).*

We request grey-time observation in the SDSS z' band with the KPNO-4m telescope (Mosaic imager). For each target, we require 60 minutes of integration time split into 6 exposures to reach a limiting magnitude of 23.1 (point source $S/N = 10$). For this band, we restrict observations to airmass< 1.8. Including observation+readout time, with 30 minutes for observing photometric standards each night, we require 2 nights of observation in S09A and 1 night in S09B. There is some freedom to adjust the allocation between the two semesters, as discussed in the description for observing run 1.

Instrument Configuration

Filters: z'	Slit:	Fiber cable:
Grating/grism:	Multislit:	Corrector:
Order:	λ_{start}:	Collimator:
Cross disperser:	λ_{end}:	Atmos. disp. corr.:

R.A. range of principal targets (hours): 0 to 16

Dec. range of principal targets (degrees): -2 to 67

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

Target Table for Run 3: KP-4m/MOSA

Obj ID	Object	α	δ	Epoch	Mag.	Filter	Exp. time	# of exp.	Lunar days	Sky	Seeing	Comment
1	ABELL0068	00:36:59.4	09:08:30.1	J2000		z'	600	6	9	phot	1.1	(WL Oct 08)
2	ABELL0267	01:52:41.9	01:00:25.6	J2000		z'	600	6	9	phot	1.1	WL
3	PHOTOZ02	02:30:00.0	00:00:00.0	J2000		z'	600	6	9	phot	1.1	calibration field
4	ABELL0586	07:32:20.5	31:38:14.6	J2000		z'	600	6	9	phot	1.1	(WL Dec 08)
5	ABELL0611	08:00:56.8	36:03:23.6	J2000		z'	600	6	9	phot	1.1	WL
6	ABELL0665	08:30:45.2	65:50:34.7	J2000		z'	600	6	9	phot	1.1	WL
7	ABELL0697	08:42:57.5	36:21:59.3	J2000		z'	600	6	9	phot	1.1	WL
8	ABELL0773	09:17:53.4	51:43:37.3	J2000		z'	600	6	9	phot	1.1	WL
9	ABELL0963	10:17:03.6	39:02:49.4	J2000		z'	600	6	9	phot	1.1	WL
10	ZwCl3146	10:23:39.6	04:11:10.7	J2000		z'	600	6	9	phot	1.1	(WL Dec 08)
11	ABELL1576	12:36:59.2	63:11:11.7	J2000		z'	600	6	9	phot	1.1	(WL Dec 08)
12	ABELL1682	13:06:50.0	46:33:33.4	J2000		z'	600	6	9	phot	1.1	(WL Dec 08)
13	ABELL1689	13:11:29.5	-01:20:27.9	J2000		z'	600	6	9	phot	1.1	WL
14	ABELL1758	13:32:35.8	50:28:55.0	J2000		z'	600	6	9	phot	1.1	WL
15	ABELL1763	13:35:20.0	41:00:04.1	J2000		z'	600	6	9	phot	1.1	(WL prop. pending)
16	ABELL1835	14:01:02.0	02:52:42.5	J2000		z'	600	6	9	phot	1.1	WL
17	ABELL1914	14:26:03.8	37:49:53.4	J2000		z'	600	6	9	phot	1.1	WL
18	ABELL2111	15:39:40.4	34:25:27.3	J2000		z'	600	6	9	phot	1.1	(WL prop. pending)